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Impact of Electric Vehicle Loads on Utility Distribution Network Voltages

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Impact of Electric Vehicle Loads on Utility Distribution Network Voltages

by

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Dedication

This work is dedicated to my mother, Dr. Usha Dubey and my grandfather Mr. Heeralal Mishra, whose encouragement and support made it possible, and to the memory of my father, Late Mr. Rakesh Kumar Dubey, who always inspired me to pursue my dreams.

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Abstract

Impact of Electric Vehicle Loads on Utility Distribution Network Voltages

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This work evaluates the impact of electric vehicle loads (EVs) on utility distribution secondary networks and determines the factors affecting the network voltage quality. The study is conducted using two actual distribution circuits, residential and mix residential and industrial circuits. The study reveals the following. A distant secondary network experiences a greater steady-state voltage drop than a nearby secondary network. Location of EV loads relative to the service transformer affects the secondary voltage more significantly. An EV load installed on a distant load node from a service transformer causes comparatively higher undervoltage condition (about 1.5%) than an EV on a nearby load node from the service transformer (about 0.75%). Increasing the size of EV charger increases the severity of an undervoltage condition. A 240V/30A EV charging station causes undervoltage condition to double compared to that of a 240V/16A EV charger. Also installing an EV load adjacent to the existing EV load customer approximately doubles the undervoltage condition at the EV load nodes.

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Chapter 1: Introduction

Electric vehicles (EV) are expected to gain market acceptance in the next few years. This trend may accelerate due to advances in battery and fast charging technologies coupled with generous federal incentives. As the number of EVs increases, so does the electricity demand required to charge their batteries. Previous EV integration studies focused on analyzing generation capacity and planning for meeting the increased demand due to EV charging [1-4]. Another study analyzed the effects of harmonic distortion on the life of distribution transformers and developed tools to determine the optimum charging conditions [5]. Unfortunately, none of these studies specifically address voltage quality impacts at the customer level, i.e., on the 120/240 V secondary network.

A prime motive of utilities is to ensure better quality electricity to the primary and secondary distribution customers. This requires a better understanding of the impacts of EV loads, so that appropriate planning measures could be taken to improve the distribution network voltage profile. This study examines impacts of EV loads on the utility distribution network and determines various factors affecting the network voltage quality. The factors considered include, distance of the service transformer from the substation, location of the EV charging station within the secondary network, size of the EV charging station (240V/16A or 240V/30A) and the effect of adding an additional EV charging station adjacent to an existing charging facility. The impact of EV charging station on the primary feeder is also evaluated and compared.

1.1 MOTIVATION AND ANALYSIS APPROACH

In order to ensure a better voltage quality, an understanding of the impacts of EV loads on the utility distribution network is required. Once the operating and system conditions giving rise to poor voltage quality are determined, the utilities could develop various mitigation plans and contingencies to counter them. In this work, various factors that affect the voltage quality of the secondary distribution networks are evaluated. The analysis is performed on actual distribution networks and various charging scenarios are simulated based on the EV charger characteristics and the likely customer behaviors.

The study begins with the development of a multi-phase steady-state load flow model of the distribution network being evaluated. Two different distribution network models are considered, one with only residential loads and the other with both residential and commercial loads. These distribution networks are converted from CYMDIST [7] to OpenDSS [8] platform. The circuit models in OpenDSS are validated against the original distribution feeder models in CYMDIST by comparing results of load flow and short circuit analysis. Details for the conversion and validation of the distribution networks are given in Chapter 2 and Chapter 3.

Evaluation of the impacts of EV load on voltage quality of the distribution network requires simulation and comparison of load flow solutions with and without EV loads. For this purpose, it is required to capture daily variations in conventional loads. This is done by simulating load flow solutions at hourly intervals for a day, referred to as 'daily load flow solutions'. Clearly, it requires daily load shape profiles for all the conventional loads present in the distribution feeder. These are generated and assigned using the kW consumption data (measured at the substation) for Year 2011 and the stratified pricing information. A detailed method for obtaining the load shapes for conventional loads is given in Chapter 3, Section 3.2.

The next step is the generation of an OpenDSS model for the EV loads. In this work, EV loads are modeled as a constant power load with an associated load shape. Based on the temporal diversity in EV load charging patterns and the characteristics of the secondary circuit, load shapes for EV loads are generated (details in Chapter 4). Level-2 (AC) EV chargers with a voltage rating of 208V/240V are considered in the study. Level-2 (low) and Level-2 (high) chargers with a power rating of 3.84 kW (240V/16A) and 7.2 kW (240V/30A), respectively are evaluated in this work. The charging efficiency of 90% is assumed for all EV chargers considered.

EV loads can impact the voltage quality of primary and secondary networks. For this reason, various charging scenarios are simulated and evaluated for their impact on the voltage variation of the distribution network. The work could be categorized in three major parts:

1.1.1. Evaluation of the voltage variation on the secondary network connected to a single-phase service transformer with one EV load

This section evaluates various circuit parameters that affect the voltage quality of a single-phase secondary network. The secondary network under evaluation is populated with one EV charging station and the circuit parameters are varied depending upon the evaluation case. It should be noted that in this case the EV charging station is connected to a residential facility. In order to generalize the analysis for a multi-family residential dwelling, the EV charging station is assumed to be sequentially charging multiple EVs from 6 pm to 8am. Hence this analysis generalizes the impact of EVs connected to both, a single-family and a multi-family residential facility. Illustration 1.1-1 summarizes various charging scenarios that were simulated. The following evaluation cases are considered for the analysis:

1. Location of the service transformer with respect to the substation
2. Location of the EV load with respect to the service transformer
3. Size of the EV load (240V/16A vs. 240V/30A)
4. Effects of adding an additional EV load adjacent to the existing EV load

1.1.2. Evaluation of the voltage variation on the secondary network connected to a three-phase service transformer with three EV loads

This section evaluates the impact of the location of a three-phase secondary network on its voltage quality. The secondary network under evaluation is populated with three EV loads that are connected in a balanced configuration. For comparison, the location of the service transformer with respect to the substation is varied to get two different evaluation cases, one with the service transformer remote from the substation and the other close to the substation. Illustration 1.1-2 summarizes the evaluation conditions.

1.1.3. Evaluation of the voltage variation on the primary network

The impact of the location of secondary network with respect to the substation on the voltage quality of primary network is evaluated in this section. The selected secondary network is loaded with 50% to 100% EV penetration. Two different cases are simulated (secondary network is remote/nearby the substation) and are compared for the voltage drop in the primary wires. Illustration 1.1-3 summarizes the evaluation conditions. Also in this case the charging stations (connected to a residential facility) are assumed to be serving multiple electric vehicles sequentially.

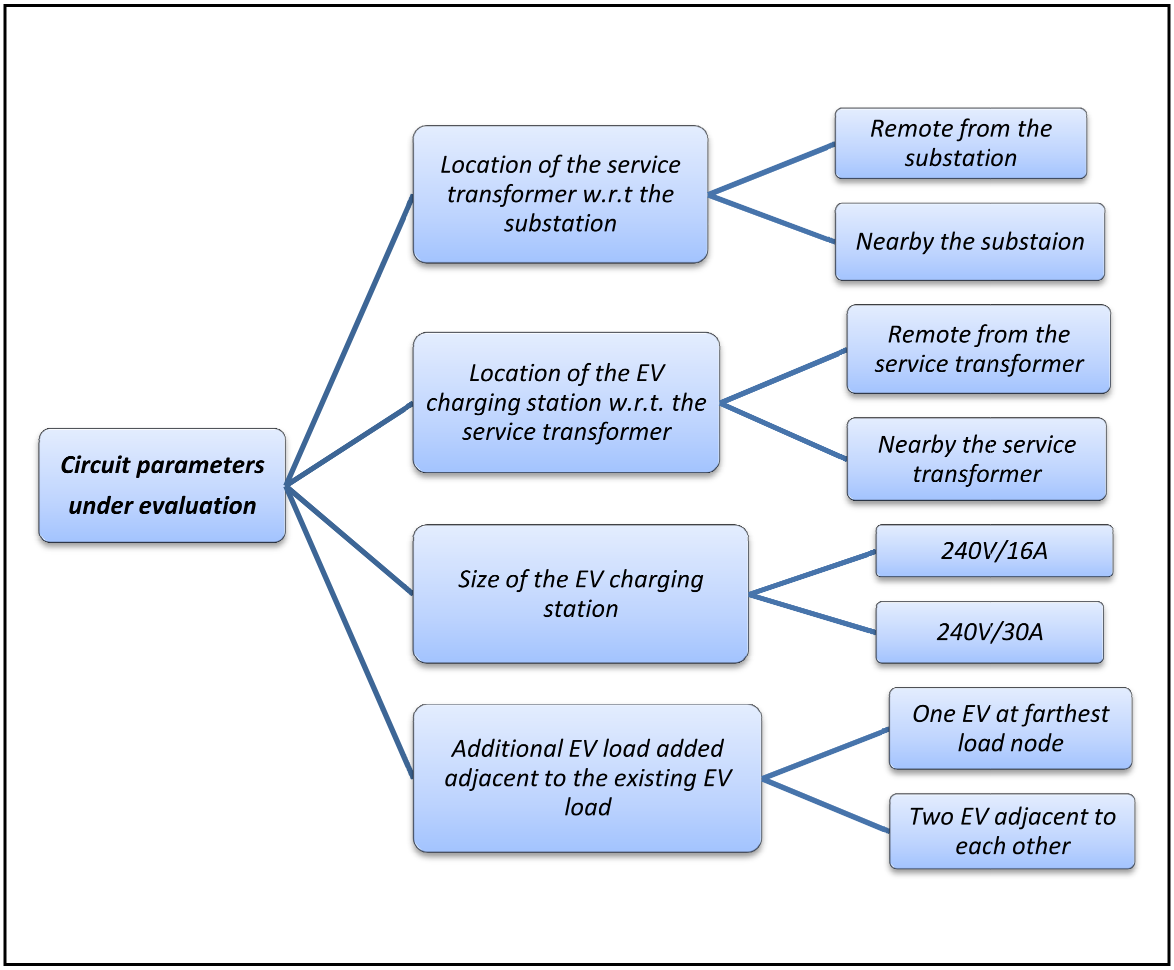


Illustration 1.1-1: Various factors evaluated for their impact on the voltage variations of the single-phase secondary network loaded with one EV charging station

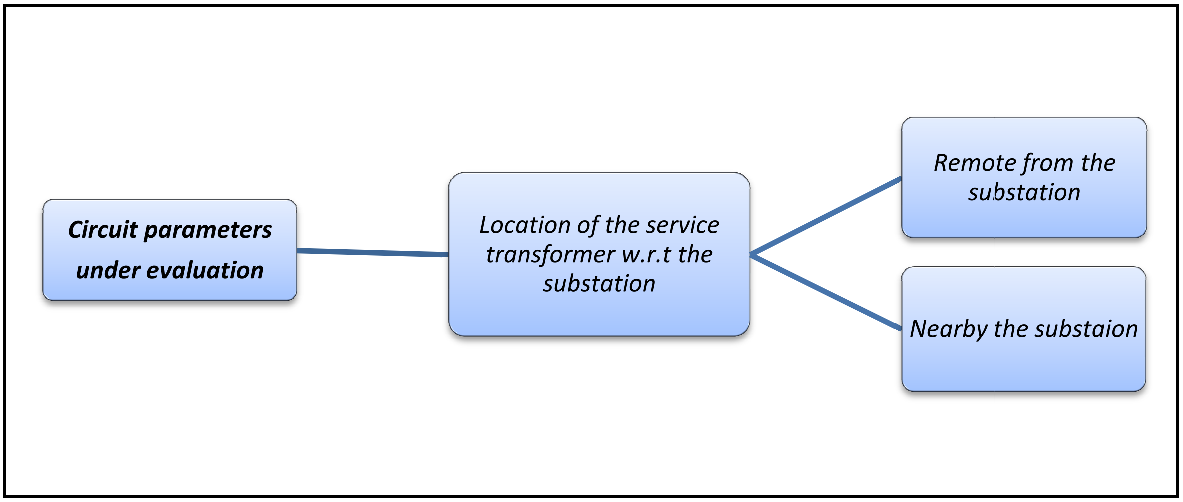


Illustration 1.1-2: Factors evaluated for their impact on the voltage variations of the three-phase secondary network loaded with three EV charging stations

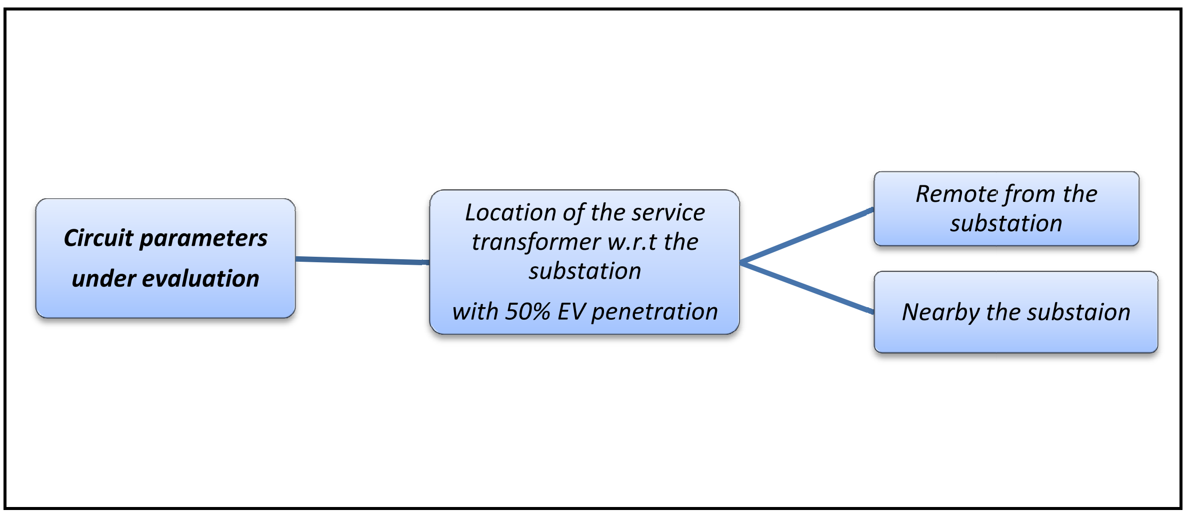


Illustration 1.1-3: Evaluations of the voltage variation on the primary network with 50%-100% EV penetration in the secondary network

1.2 SUMMARY

Factors affecting secondary network voltage profile due to charging of the electric vehicles (EVs) are identified and evaluated. Fortunately, most severe voltage drop occurs at the EV load node itself. Other non-EV load nodes are not impacted unless they lie along the path of the charging current. The amount of voltage drop is attributed to the line impedance present in the secondary wire. The key observations made from the analysis are as follows:

- EV loads causes more severe effects on the voltage quality of the secondary network as compared to the primary feeder.
- The voltage drop for a secondary network that is far from the substation is greater than the secondary network closer to the substation.
- An EV load within the secondary network at the farthest load node from the service transformer causes more voltage drop than one at the nearby load node.
- The voltage drop due to a 240A/30A EV charging station is approximately double of the 240V/16A EV load.
- An additional EV load added adjacent to an existing EV load increases the undervoltage in the secondary network under evaluation.
- An EV load connected to a three-phase service transformer shows similar effects on the voltage quality of the secondary network as an EV load connected to a single-phase service transformer.

Detailed summary of the study conducted on the residential and the mixed circuit for various potential factors that could affect the voltage quality is presented in the tables below.

Circuit parameters under evaluation	***Different conditions evaluated for***	***Largest voltage drop***		***Condition for the largest voltage drop***
		Residential circuit	*Mixed circuit*	
Location of the service transformer w.r.t the substation	Remote from the substation	1.5%	1.5%	Service transformer remote from the substation
	Nearby the substation	1%	1%	
Location of the EV charging station w.r.t. the service transformer	Remote from the service transformer	1.5%	1.5%	EV load remote from the service transformer
	Nearby the service transformer	0.75%	0.123%	
Size of the EV charging station	240V/16A	1.5%	1.5%	EV load of Size 240V/30A
	240V/30A	3.15%	2.8%	
Additional EV load added adjacent to the existing EV load	One EV load	1.5%	1.5%	Additional EV load increases the voltage drop
	One+One EV load	2.8%	1.8%	

Table 1.2-1: Summary of effects of various factors evaluated on the secondary network supplied by a single-phase service transformer (One EV load)

Circuit parameters under evaluation	***Different conditions evaluated for***	***Largest voltage drop Mixed residential and commercial circuit***	***Condition for the largest voltage drop***
Location of the service transformer w.r.t the substation	Remote from the substation	0.54%	Service transformer remote from the substation
	Nearby the substation	0.123%	

Table 1.2-2: Summary for the effects of the EV charging on the secondary network supplied by a three-phase service transformer (Three EV loads)

Circuit parameters under evaluation	***Different conditions evaluated for***	***Largest voltage drop in the primary of the service transformer***		***Condition for the largest voltage drop***
		Residential circuit	*Mixed circuit*	
Location of the service transformer w.r.t the substation	Remote from the substation	0.12%	0.02%	Service transformer remote from the substation
	Nearby the substation	0.01%	0.005%	

Table 1.2-3: Summary for the effects of the EV charging on the primary network (50%-100% EV penetration)

Chapter 2: Development of the Data Converters from CYMDIST to OpenDSS

Actual distribution models provided were given in CYMDIST platform. For EV charging analysis, a simulation platform more flexible in terms of modeling new components and modifying charging scenarios is required. For this purpose, the distribution network model (available in CYMDIST) is exported to the EPRI's open source distribution simulator (OpenDSS). This chapter summarizes the procedure for converting the distribution system electrical model from CYMDIST to OpenDSS.

2.1 CYMDIST - Distribution System Analysis

The CYMDIST [7] Distribution Analysis software is a suite of applications composed of a network editor, analysis modules and user-customizable model libraries. The program is designed for planning studies and simulating the behavior of electrical distribution networks under different operating conditions and scenarios. It includes several built-in functions that are required for distribution network planning, operation and analysis. The analysis functions such as load flow short-circuit, and network optimizations, are performed on balanced or unbalanced distribution network that are built with any combination of phases and configurations. CYMDIST includes a full network editor and various analysis modules for:

- Unbalanced load flow
- Comprehensive fault analysis
- Load balancing
- Load allocation/estimation
- Optimal capacitor placement

Two different types of distribution networks are provided by the utility in .sxst file (CYMDIST format). Though CYMDIST is pretty versatile in its application modules, we require more flexibility in terms of modeling new loads. For modeling EV charging station we require a simulation platform more flexible in terms of modeling new components and modifying charging scenarios. Hence to facilitate the analysis, the distribution system model is converted from CYMDIST to OpenDSS.

2.2 OpenDSS - Open Distribution System Simulator

The Open Distribution System Simulator (OpenDSS) [8] is a comprehensive electrical system simulation tool for electric utility distribution systems. OpenDSS refers to the open-source implementation of the DSS. The program basically supports all frequency domain (sinusoidal steady-state) analyses commonly performed for utility distribution systems. Additionally, sequential power flows can be simulated over successive time intervals (e.g., hourly or yearly) for a specified period of time. This capability allows us to perform the daily and yearly load flow study for the distribution system with consideration to the variations in EV load patterns and daily and yearly conventional load variations.

In addition, it supports many new types of analyses that are designed to meet future needs. Many of the features found in the program were originally intended to support distributed generation analysis needs. Other features support energy efficiency analysis of power delivery and harmonics analysis. The DSS is designed to be indefinitely expandable so that it can be easily modified to meet future needs.

For illustration purposes, a small test circuit (testCKT.sxst) with around 20 secondary networks and 300 devices is created using a distribution network model and converted from CYMDIST to OpenDSS. The small test circuit is initially created to aid the basic understanding of the conversion process and reduce the burden of managing large amount of circuit data. Once this process is well understood and validated, it is performed on the entire distribution system model. The steps to create a small test circuit from the distribution system model are discussed in the following section.

2.3 Steps to Create a Test Circuit

The test circuit (testCKT.sxst) shown in Fig. 2.3-3 is a small segment of the residential distribution network (residentialCKT.sxst) available in CYMDIST. It consists of a primary feeder, few secondary networks and around 300 devices including single and three-phase loads. To create the test circuit, first the load allocation is done for the residentialCKT.sxst using CYMDIST. The test circuit is then disconnected from the rest of the residential circuit and is saved as a new CYMDIST study file, testCKT.sxst.

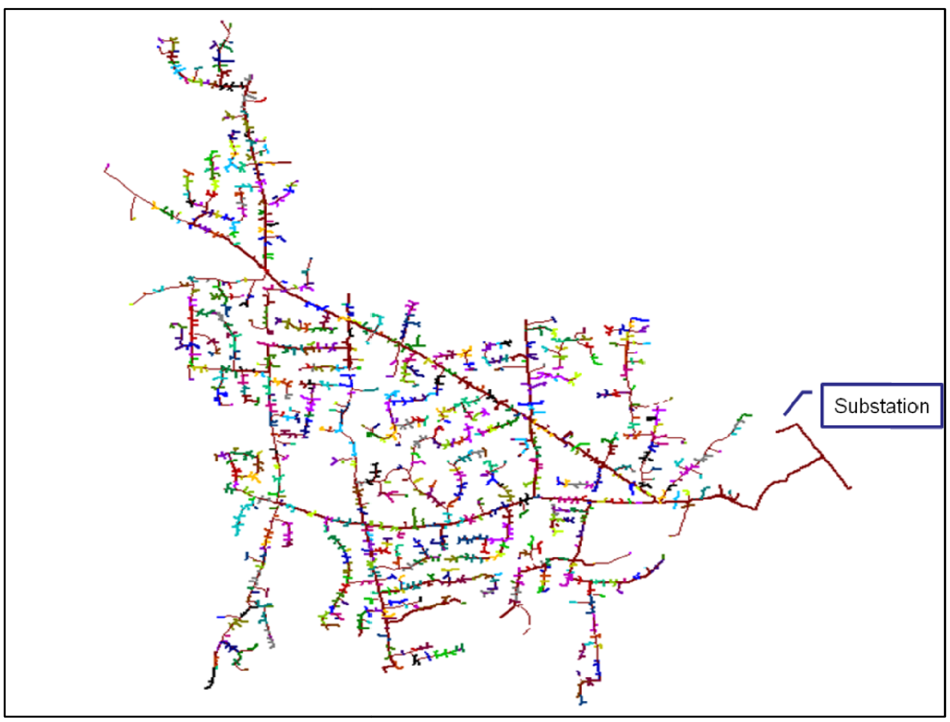


Fig. 2.3-1: One line diagram for the distribution circuit in CYMDIST

2.3.1 Load allocation

Load allocation is the process of distributing kW or Amps per phase load at a given point to the individual circuit elements downline from that point. It gives a close approximation of the actual loading at each load point. For the residential distribution circuit model (residential.sxst), load allocation is done using CYMDIST. CYMDIST assigns a portion of the metered demand to each phase of each section according to the kVA (connected or actual), kWh consumed and number of consumers connected there. The steps to allocate loads using CYMDIST are as follows:

1. Open the full distribution network model in CYMDIST.
2. Allocate loads to it by using CYMDIST toolbar; go to Analysis and then Load Allocation.

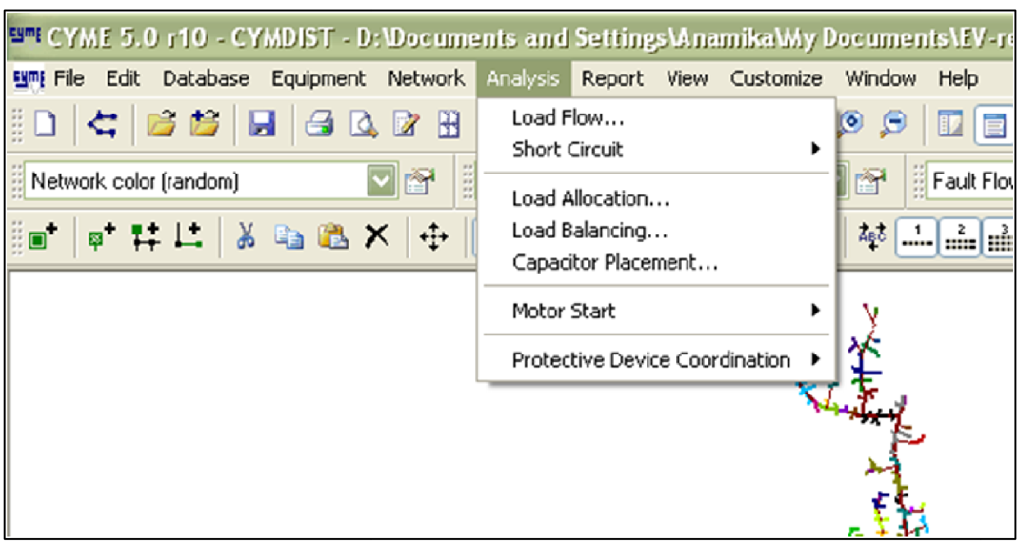


Fig. 2.3-2: Load allocation in CymeDist

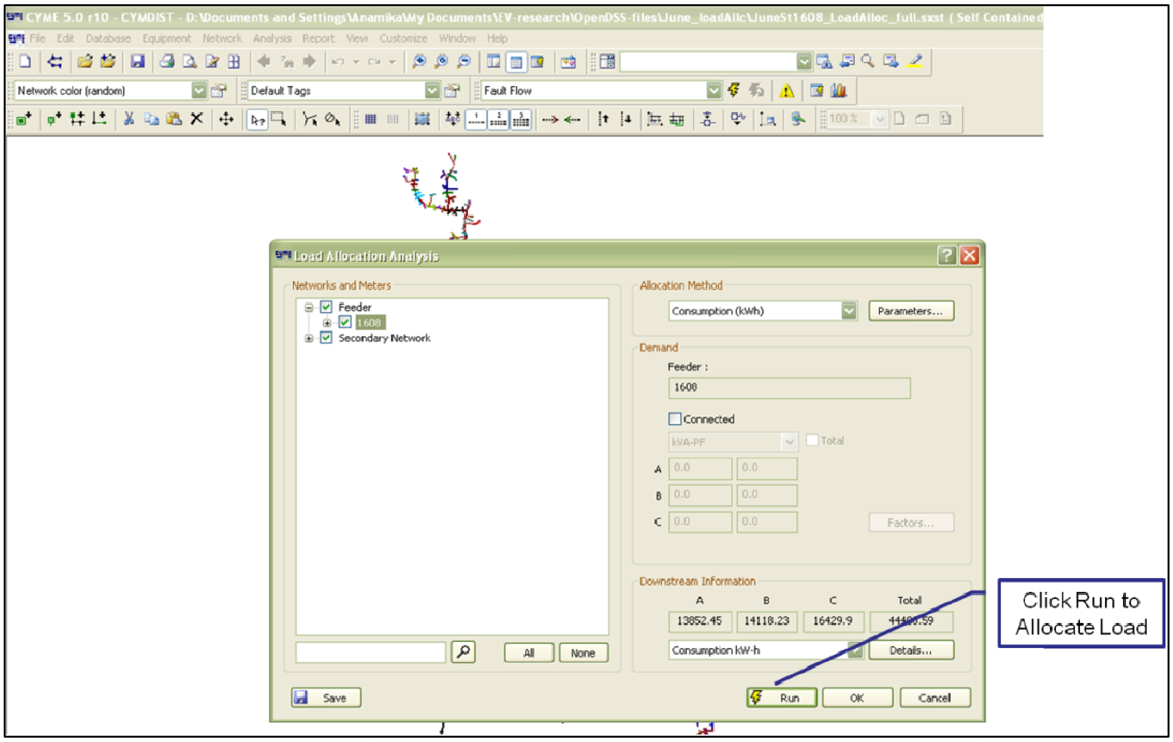


Fig. 2.3-3: Click Run to allocate load

2.3.2 Create the test circuit

Once the load allocation is done, the test circuit is created using the residentialCKT.sxst file. A small set of primary and secondary feeders starting from the substation are selected from the network and rest of the feeders are disconnected. This circuit is then saved as a new file, testCKT.sxst. The test circuit generated in shown in Fig. 2.3-3. It contains 665 nodes, 267 lines and 310 devices including transformers loads, and capacitor banks . Steps to create the test circuit are summarized as follows.

1. Start from the substation and select a small set of primary and secondary feeders from full network.
2. Disconnect rest of the network to obtained the test network suitable for initial study
3. Save the circuit as testCKT.sxst

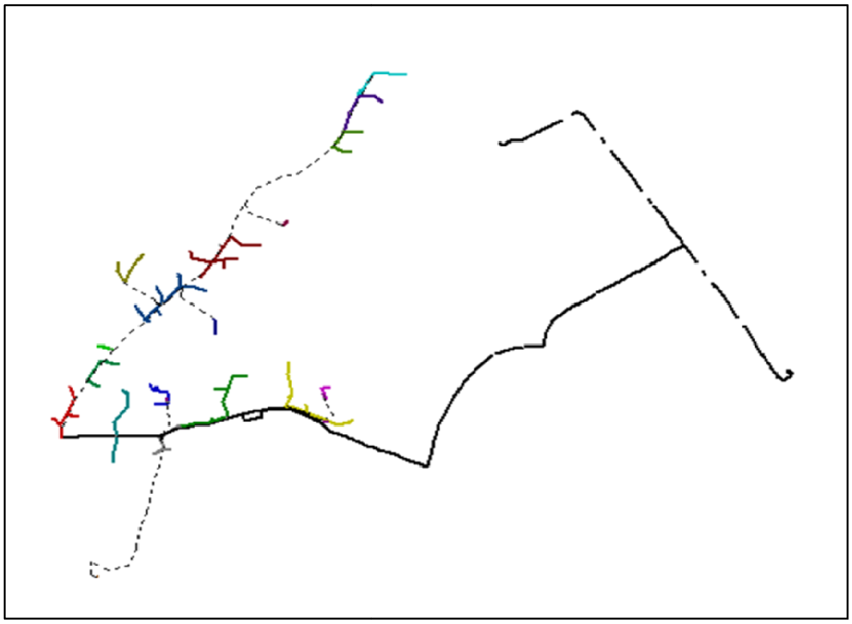


Fig. 2.3-4: One line diagram for the test circuit, testCKT.sxst

2.4 CONVERSION FROM CYMDIST TO OPENDSS

The conversion steps for the distribution system model from CYMDIST to OpenDSS are summarized in this section. The distribution circuit considered for this study is the test circuit (testCKT.sxst) shown in Fig 2.3-3. Once this method is validated for the small test circuit, the complete residential distribution feeder model (Fig. 2.3-1) is exported from CYMDIST to OpenDSS and validated using load flow and short circuit analysis. The application tools used for exporting the distribution system model from CYMDIST to OpenDSS are MS Access 2007 (or higher) and Visual Basic for Applications (VBA).

The conversion of the network model from CYMDIST to OpenDSS is a two stage process. The first step is to export circuit data from CYMDIST to MS Access tables, followed by visual basic programming to translate the distribution network model present in MS Aceess tables to OpenDSS. A detailed algorithm for the conversion process is given in Illustration 2.4-1.

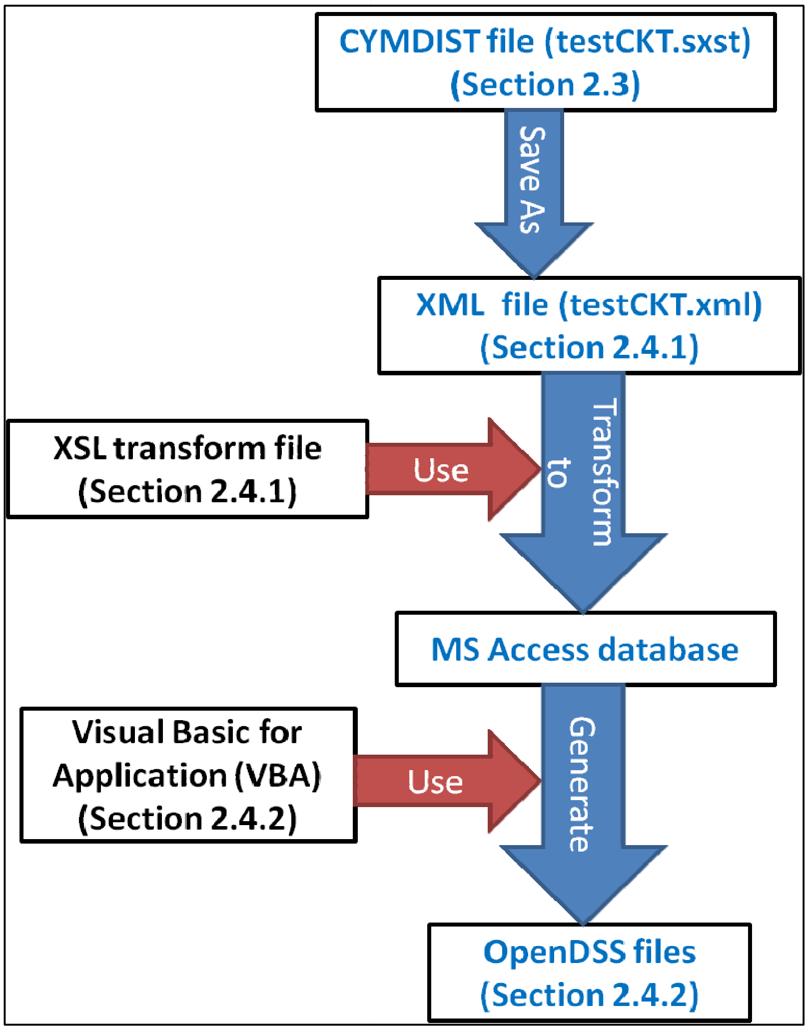


Illustration 2.4-1: Exporting data from CYMDIST to OpenDSS

The detailed conversion process along-with the required application tools and sample code snippets is discussed in the following section. The discussion is divided in two parts. First, giving details of the data export from CYMDIST to MS Access (Section 2.4.1), along-with details of the application tools, file structure and steps of conversion.

The second part (Section 2.4.2) gives a detailed explanation of the programming using Visual basic for application (VBA) to generate required DSS files for the circuit model.

2.4.1 Exporting Data from CYMDIST to MS Access

The test circuit (testCKT.sxst) in CYMDIST is exported to MS Access table using Extensible Markup Language (XML) and EXtensible Stylesheet Language (XSL). The data available in CYMDIST file (.sxst) is first encoded using XML. The encoding in XML is done simply by saving the CYMDIST (testCKT.sxst) file as testCKT.xml. A XSL transformation file (XSLT) is written using EXtensible Stylesheet Language (XSL) to transform the XML file into MS Access tables. The encoded XML file is then transformed using this XSLT file and tables are generated for each circuit component present in the circuit model. The section below describes the XML file structure and basic programming guidelines to create the XSL transform file. The steps for exporting the circuit data from CYMDIST to MS Accees are summarized below:

- First save the CYMDIST file (testCKT.sxst) as XML i.e. testCKT.xml
- Using an XSL transform file, transform the XML file (testCKT.xml) to MS Access tables.

Files needed to export the data from CYMDIST to MS Access

To export data from CYMDIST to MS Access, CYMDIST (testCKT.sxst) data file and XSL transform file are required.

1. Data file: A CYME (textCKT.sxst) file containing a small test network derived from the complete distribution network. (described in Section 2.3)
2. XSL Transform File - This file is used to transform data in a CYMDIST file (for ex. testCKT.sxst) file to the MS Access tables

Structure of the .xml file

As discussed earlier, first the testCKT.sxst file is stored in XML format. The structure of the XML file is shown in Fig. 2.4-1. The XML file categorizes various network devices, feeders and nodes under “Networks” and equipment definitions under the “Equipments”. Hence, the data corresponding to the feeders, loads, capacitor, transformer and other devices present in the distribution network are categorized as “Networks” and the transformerCodes, lineCodes, loadShapes which define the network element are categorized as “Equipments”. This XML structure is then used by the XSL transform file (XSLT) to export the structured data into MS access tables.

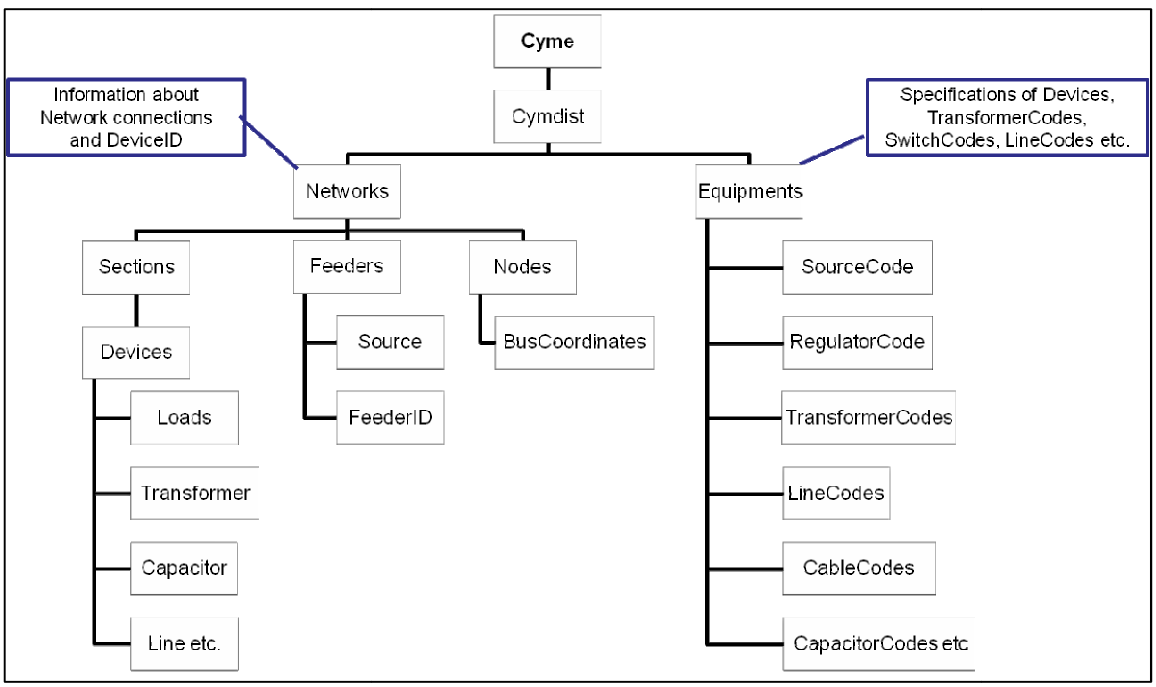


Fig. 2.4-1: Structure of the XML file

Procedures to write the XSLT transform files

XSLT file is written using XSL (EXtensible Stylesheet Language), a style sheet language for XML documents. XSLT stands for XSL Transformations. Using these files, XML documents could be transformed to other file formats like MS Access tables in our work. The procedure for writing XSLT files for this application is as follows.

1. The objective is to generate tables corresponding to the data given in both Networks and Equipment elements of the XML file. Note that XML file is obtained by saving the CYMDIST file as XML file.
2. XSL uses “<xsl:template match>” property to read data in various elements of the xml file.
3. A sample code snippet of an XSL file is given below.

```
<xsl:template match="/Cyme">
        <Cyme>
        <xsl:apply-templates select="Cymdist"/>
        </Cyme>
</xsl:template>
```

In this code snippet the XSL file is searching for “Cyme” element in the testCKT.xml. Once the "Cyme" element is found, XSL looks for its child element “Cymdist” and selects it using “xsl:apply-templates” property. The next step will be to look for child elements of “Cymdist".

4. In the code snippet given below the XSLT is looking for “Cymdist” element and then selecting its child elements, viz. "Networks" and "Equipmets" using apply template property. In this way it reads the entire XML data structure.

```
<xsl:template match="Cymdist">
        <xsl:apply-templates select="Networks"/>
        <xsl:apply-templates select="Equipments"/>
</xsl:template>
```

5. XSLT then extracts the data stored in the XML nodes and adds it to the output stream of the MS Access table. For this purpose XSL uses its "<xsl:value-of>" property and extracts value of different properties defined for a circuit element..
6. Based on the above discussion, let us try to understand the code snippet given below. In this code the XSLT is using the XML file to generate MS Access table for the network bus coordinates.

```
<xsl:template match="Nodes">
        <xsl:apply-templates select="Node"/>
</xsl:template>
<xsl:template match="Node">
<BusCoordinates>
        <NodeID>
                <xsl:value-of select="NodeID"/>
        </NodeID>
        <X>
                <xsl:value-of select="X"/>
         </X>
         <Y>
                <xsl:value-of select="Y"/>
        </Y>
        </BusCoordinates>
</xsl:template>
```

The XSLT file starts the conversion by looking the "Nodes" element the distribution network XML file using template match property (<xsl:template match="Nodes">). Once "Nodes" element is located XSLT selects its child element "Node" using apply template property (<xsl:apply-templates select="Node"/>).

The next step is to define the MS Access table structure and export the node data from the XML file. The XSL transform file then defines a table named "BusCoordinates", with three data field (columns) namely, "NodeID", "X" and "Y". The value stored in data fields of "Node" element in the XML file are then transferred to the respective columns of the "BusCoordinates" table, using XSL value-of property. For instance, <xsl:value-of select="NodeID"/> - exports the NodeID data to NodeID column of the "BusCoordinates" table and “<xsl:value-of select="X"/>” and “<xsl:value-of select="Y"/>” export the X and Y coordinates of the Node to the respective columns of the "BusCoordinates" table.

7. In this way the XSL transform file is written for all the circuit elements to export the network data present in the XML files into MS access database.

<u>Steps to Export data from CYMDIST to MS Access</u>

This section summarizes the steps needed to export the data from CYMDIST to MS Access tables. Snapshots are provided corresponding to every step to facilitate the application handling during the conversion process.

1. Store the testCKT.sxst (cyme file) as an XML (testCKT.xml) file.
2. Create a new database in MS Access using new command as shown in Fig.2.4-2.

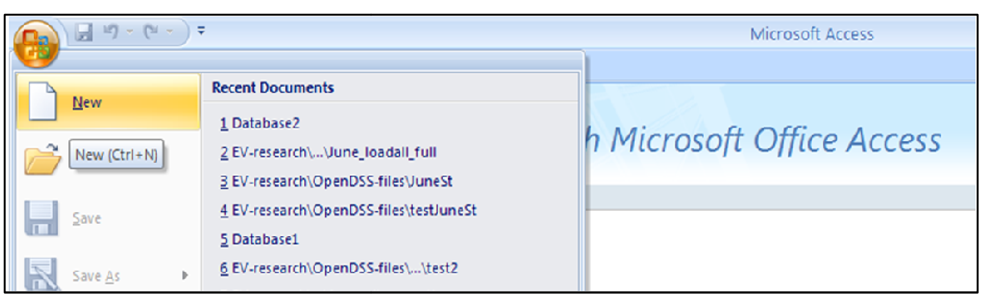


Fig. 2.4-2: Create new database in MS Access

3. In the new database: Go to External Data and select XML file option. Browse the xml file and click OK.

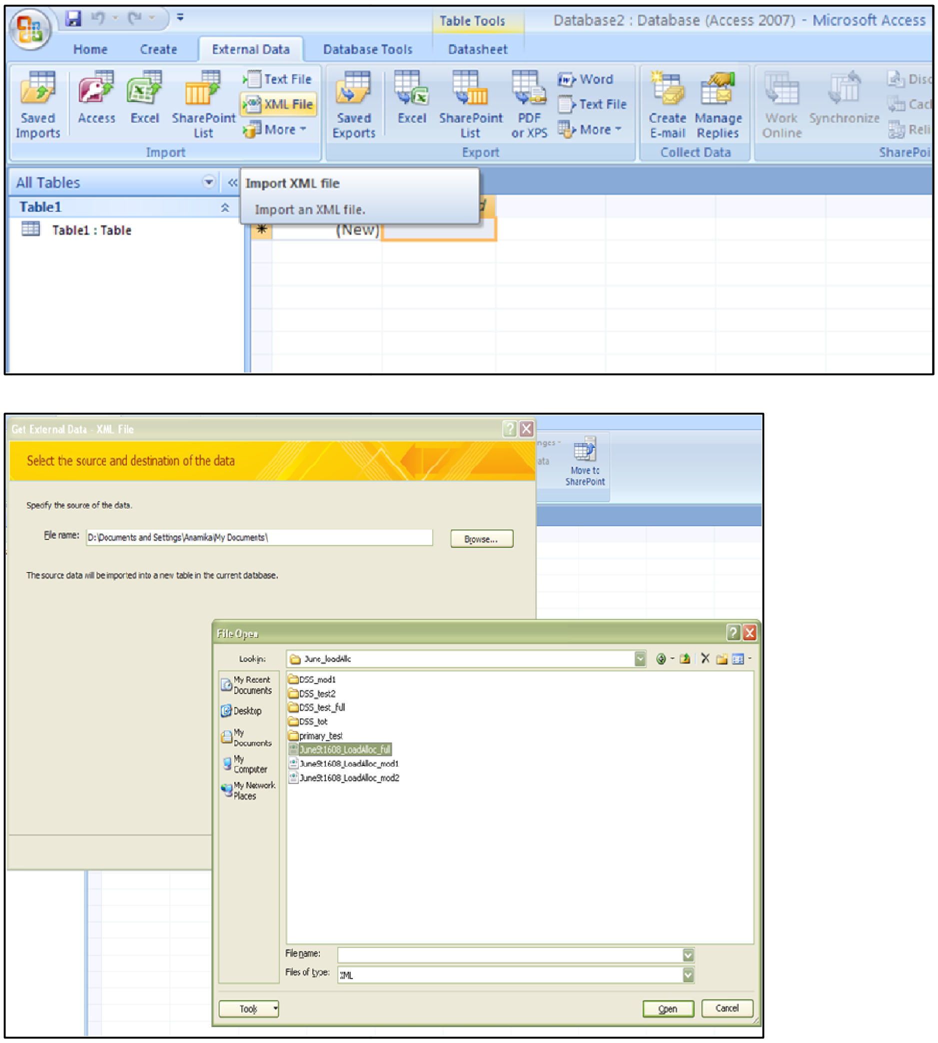


Fig. 2.4-3: Import .xml file, a). Select XML file option; b). Open the XML file

4. Select transform and browse the corresponding XSL transform file to export data into MS access database.

5. This will create separate tables for equipments present in the network i.e. lines, loads etc. Hence data is successfully exported from CYMDIST to MS Access.

2.4.2 Converting network data in MS Access to OpenDSS

The objective of this section is to create DSS files corresponding to the MS Access database obtained by exporting the testCKT.sxst file. Visual Basic for Application (VBA) is used for this purpose. The VBA programming and the steps for creating OpenDSS files for various circuit components in the network (lines, loads, source, transformers etc.) are discussed below. The section also discusses few sample VBA code snippets to understand the programming structure.

Visual Basic for Application (VBA)

Visual Basic for Applications (VBA) is an implementation of Microsoft's event-driven programming language Visual Basic 6 and its associated integrated development environment (IDE), which are built into most Microsoft Office applications. A common use of VBA is to add increased 'functionality' or some 'automation' to the various MS OFFICE programs. In this study VBA programming is used for translating the data in MS access tables into DSS files.

VBA Programming structure

This section describes few basic VBA programming structures required for translating the network data to DSS files. To begin with a module is inserted in the visual basic window of the current MS Access database. After that various sub-procedures and functions are written, in the created module for translating different tables corresponding to the specific network components into DSS files.

1. **Modules:** A module is a file that holds code or pieces of code in a Visual Basic application. Each form or report of a database has a (separate) module.
2. **Sub-Procedures:** A sub procedure is a section of code that carries an assignment but does not give back a result. To create a sub procedure, start the section of code

with the Sub keyword followed by a name for the sub procedure. The Sub keyword and the name of the procedure (including its parentheses) are written on one line. The section of the sub procedure code closes with End Sub as follows:

```
Sub ProcedureName()
End Sub
```

3. **Function:** A function is a procedure that takes care of an assignment and returns a result. A function resembles a sub procedure in all respects except that a function returns a value. A function is created like a sub procedure with a few more rules. The creation of a function starts with the Function keyword and closes with End Function. Here is an example:

```
Function GetFullName()
End Function
```

<u>VBA Programming for generating OpenDSS data files</u>

This section describes various programming structures written using VBA for our application. Specific functions for creating independent DSS files for loads, lines, transformers etc. are written. A Sub-Procedure named runall() is written to call all the function that create the DSS files. Following procedures and functions are written for this application:

1. Sub Procedure –
    - runall() – to call all the functions and generate the DSS files
2. Functions –
    - MakeMaster() – creates for master.dss
    - MakeLoadsFile() – creates DSS file for the load element (loads.dss)
    - MakeLine() – creates DSS file for line element (lines.dss)

- MakeLineCodes() – defines linecodes by creating linecodes.dss
- MakeCapacitors() – creates DSS file for capacitor element (capacitors.dss)
- MakeTransformers()–creates DSS file for transformer (transformers.dss)

<u>VBA Code Snippet</u>

In this section a few sample VBA code snippets are discussed to get a better understanding of the programming. Fig. 2.4-4 is the snapshot of the runall() sub-procedure. The procedure calls all the relevant functions that create the DSS files. The procedure is ended with "End Sub".

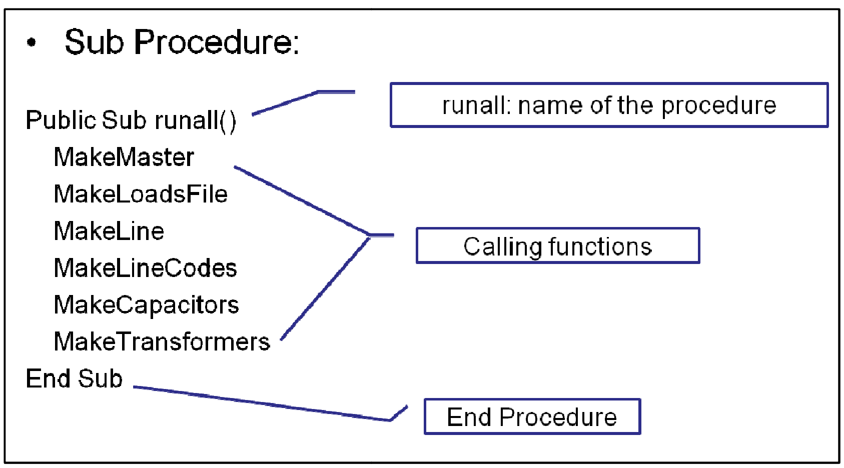


Fig. 2.4-4: VBA code snippet for the runall() Sub Procedure

The VBA code snippet for MakeLoadFile() function is shown is Fig. 2.4-5. The code generates the Loads.dss file by reading the data in the openDSS table corresponding to Loads element in the distribution model. Visual basic uses "OpenRecordset" property to read the "Loads" table present in current database and stores it as a "DAO.Recordset" object. The next step is to create a blank file "Loads.dss" and start translating the data to the file by reading rows of loads table from start to the end of the file. The detailed information about a load, like kWh demand, bus connection, phase information can be extracted by selecting the corresponding columns from the table.

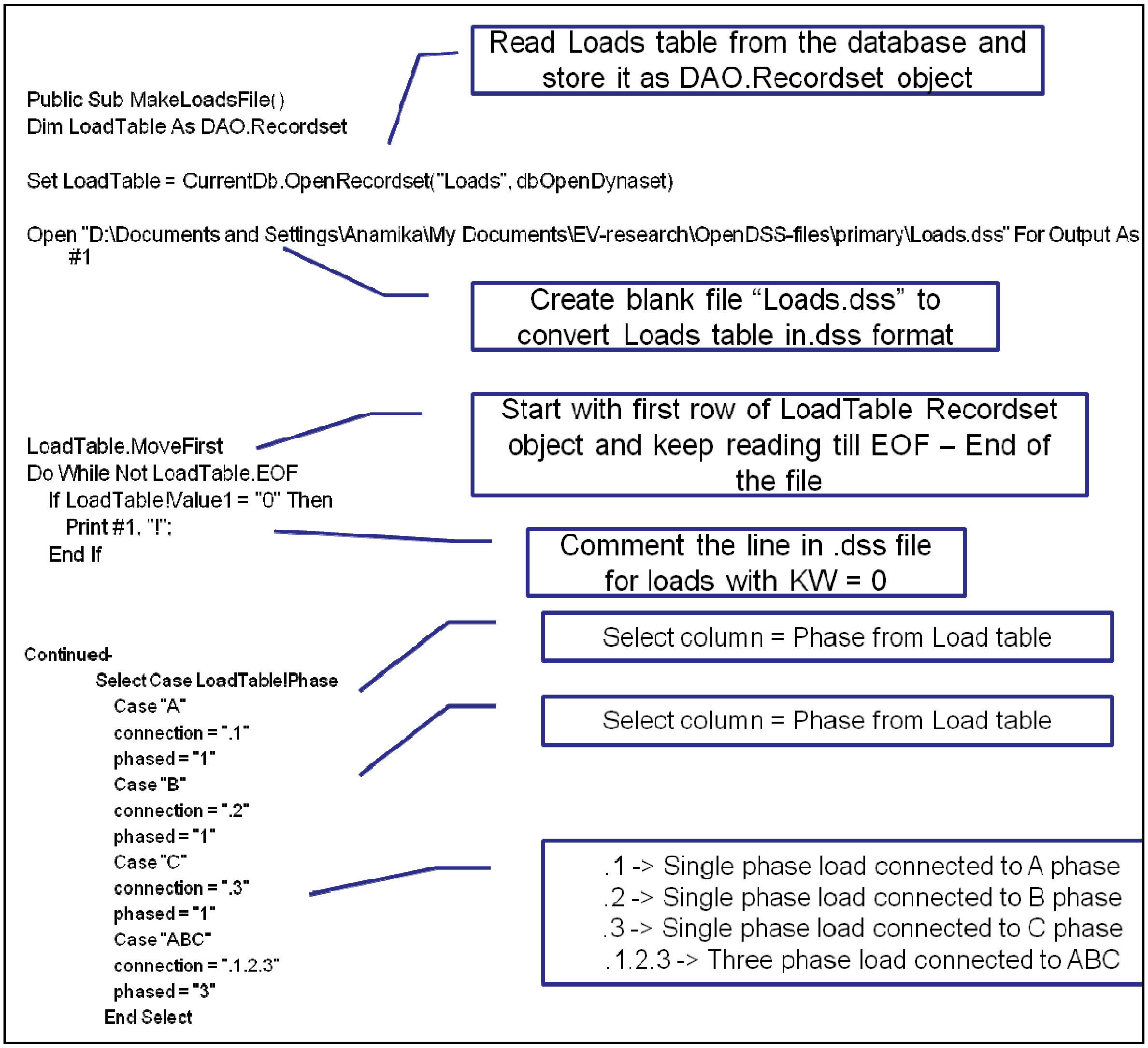


Fig. 2.4-5: VBA code snippet for the MakeLoadFile() function

The code snippet shown below gives an illustration of, how Phase and Connection information of the loads are extracted by the function. The phase and connection information about the load is extracted by selecting column "Phase" in the loads table. If it is Phase A, Phase B or Phase C, then phase information for load is written as single and the connection as ".1" for Phase A, ".2" for Phase B and ".3" for Phase C. A load with Phase = "ABC" is written as three-phase load and the load connection is ".1.2.3". In this similar way the complete information of the load table is transferred to "Loads.dss".

Sample OpenDSS files

The OpenDSS files are generated for the testCKT.sxst. Few sample OpenDSS files are shown is this section. The code snippet shown is Fig.2.4-6 describes the master.dss file. The source is defined in second line and command is written in the master.dss file to read all the network components. Detailed VBA code for generating the OpenDSS files and the OpenDSS files corresponding to all circuit elements are discussed in the Appendix.

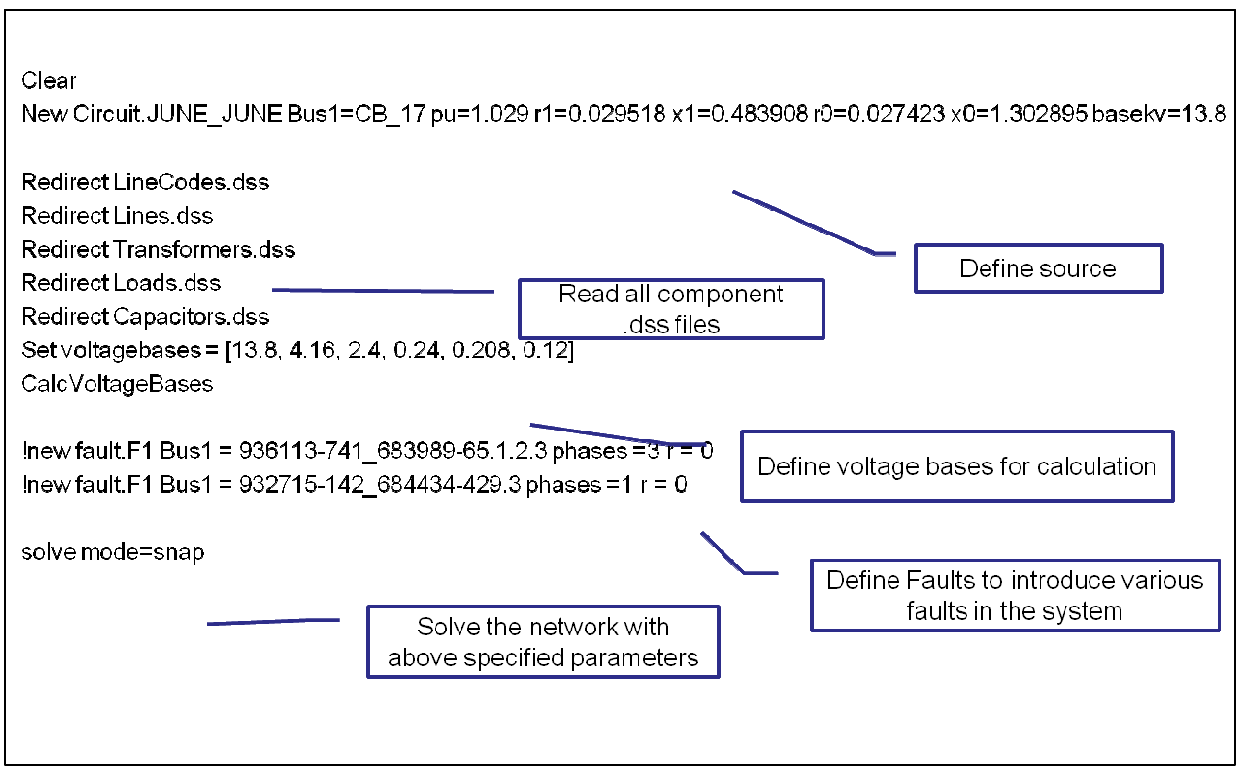


Fig. 2.4-6: Master.dss file

Steps to Export data from MS Access to OpenDSS file format

The steps to convert data from MS Access table to OpenDSS files are summarized in this section. A step-by-step instruction along-with pictorial demonstration for the same is given below.

1. Go to "Database Tools" in MS access and select Visual Basic.

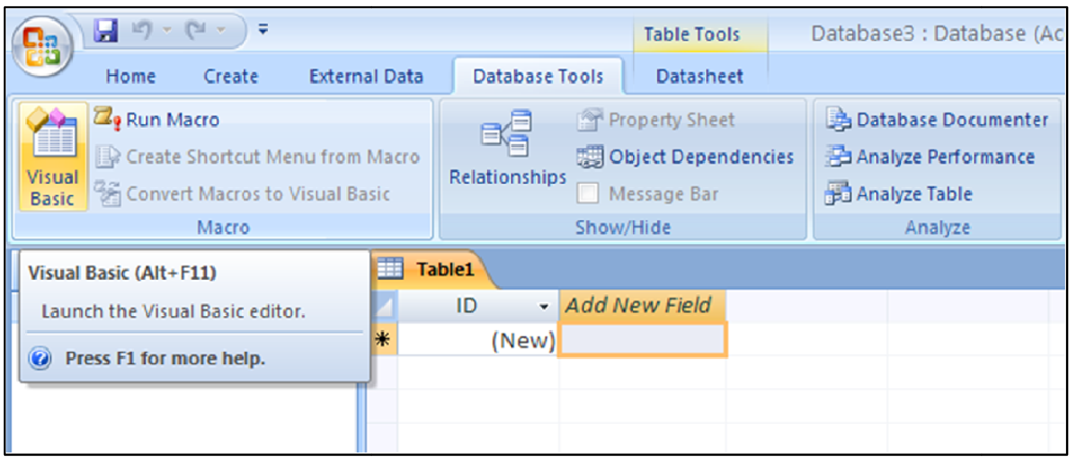


Fig. 2.4-7: Visual basic module in MS Access

2. In Visual Basic window go to Insert →Module

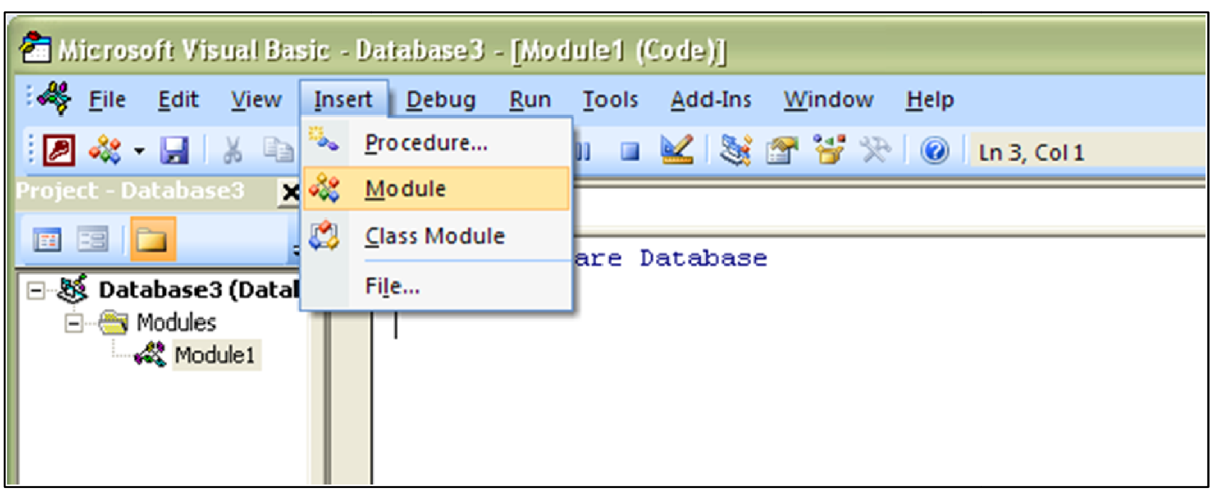


Fig. 2.4-8: Create visual basic module to generate DSS files

3. Write the visual basic module to export MS Access database into OpenDSS files.
4. Write separate functions to create DSS files for lines, linecodes, loads, transformer, shunt capacitor or any other circuit element and a master file to define substation and to call all equipment files. Also write a Sub procedure to call all the functions.
5. Run the VBA code to generate the .DSS files.
6. This process could be repeated for any distribution circuit, which has already been exported from CYMDIST to MS Access.

2.5 MODEL VALIDATION

The distribution network model for test circuit in CYMDIST (testCKT.sxst) is translated to OpenDSS using the method described in Section 2.4. The converted model (in OpenDSS) is validated against the CYMDIST model by comparing the solutions for load-flow and short-circuits analysis. A comparison of the short-circuit and load-flow analysis is shown is Tables 2.5-1 and 2.5-2. It can be seen that the percentage error recorded for the OpenDSS model is less than 0.2%, hence the data is successfully exported from CYMDIST to OpenDSS.

Bus	***CYMDIST (current through the node)***			***OpenDSS (current through the node)***			***Error (%)***
	Phase A (amp)	*Phase B (amp)*	*Phase C (amp)*	*Phase A (amp)*	*Phase B (amp)*	*Phase C (amp)*	
OH_SEC_2254016	0	23.6	0	0	23.6157	0	0.067
OH_SEC_2254018	0	23.6	0	0	23.6157	0	0.067
OH_SEC_2254020	0	23.6	0	0	23.6157	0	0.067
OH_SEC_2254010	0	46.5	0	0	46.4972	0	0.006
OH_SEC_2253977	0	23.8	0	0	23.7696	0	0.128
SEC_UG_476181	0	23.8	0	0	23.7696	0	0.128
OH_SEC_2253976	0	48.3	0	0	48.3047	0	0.01
OH_SEC_2253978	0	48.3	0	0	48.3047	0	0.01
SEC_UG_476180	0	48.3	0	0	48.3047	0	0.01
OH_SEC_2250992	0	32.6	0	0	32.5863	0	0.04
OH_SEC_2250988	0	22.2	0	0	22.2384	0	0.17
OH_SEC_2250987	0	31.6	0	0	31.5833	0	0.05

Table 2.5-1: Load flow solutions for the test circuit (testCKT.sxst)

Fault Bus	***Fault type***	***CYMDIST (Current Through The Node)***			***OpenDSS (Current Through The Node)***			***Error (%)***
		Phase A (amp)	*Phase B (amp)*	*Phase C (amp)*	*Phase A (amp)*	*Phase B (amp)*	*Phase C (amp)*	
936314.086_684060.675	LLL	16573.8	16574.3	16573.7	16576.8	16576.8	16576.9	0.0151
936113.741_683989.65	LLL	16884.9	16885.5	16884.9	16888.1	16888.1	16888.1	0.0154
937469.228_683102.05	LLL	14407.6	14407.5	14406.9	14409.7	14409.7	14409.7	0.0153
936412.61_682224.145	LLL	13001.2	13000	13000.9	13002.5	13002.5	13002.5	0.0192
934778.066_681869.697	LG-B	0	2555.7	0	0	2552.64	0	0.1197
934858.678_683975.181	LG-B	0	3022	0	0	3022.84	0	0.0278
934942.161_683924.457	LG-B	0	1641	0	0	1639.26	0	0.1060
935270.482_684612.031	LG-B	0	2087.3	0	0	2085.36	0	0.0929
1692_444493	LG-B	0	3450	0	0	3451.06	0	0.0307
933356.594_682893.034	LG-B	0	3174	0	0	3169.59	0	0.1389
933841.313_682744.106	LG-B	0	846	0	0	845.39	0	0.0721
934119.751_681960.178	LG-B	0	1200	0	0	1199.9	0	0.0083

Table 2.5-2: Short-circuit analysis for the test circuit (testCKT.sxst)

Chapter 3: Distribution System Electrical Model

Distribution system electrical models down to the residential and commercial load levels are required for the evaluation of the impact of EV loads on the distribution network. A complete electrical model of distribution circuits from the substation down to individual customer loads including three-phase transformers, three-phase primary, laterals, secondary networks, and service transformers is specified in the multi-phase steady-state load flow model. Section 3.1 describes the distribution networks evaluated in this study.

3.1 DISTRIBUTION SYSTEM ELECTRICAL MODEL

For a more comprehensive evaluation of the impact of EV loads, two different types of distribution feeders are considered. One is a residential feeder with only residential loads and the other is a mixed distribution feeder with both residential and commercial loads. The characteristics of each distribution circuit are described below.

3.1.1 Residential distribution circuit: residentialCKT

The residentialCKT distribution circuit shown in Fig.3.1-1 is supplying for mostly residential customers and contains approximately 7000 buses, supplying for over 13000 devices. The total length of the primary and secondary overhead lines and cables combined is approximately 200 km.

- Majority of the customer loads supplied by residentialCKT are single-phase. However it also serves a few two-phase and three-phase loads.
- The largest single-phase load present in the distribution network has a peak demand of approximately 8 kW.

- The daily energy consumption measured at the substation is found to be 44,400 kWh, with an approximately balanced demand (phase A - 13852 kWh, phase B - 14118 kWh, phase C - 16429.9 kWh)
- The peak kVA demand recorded at the substation is 7465 kVA.

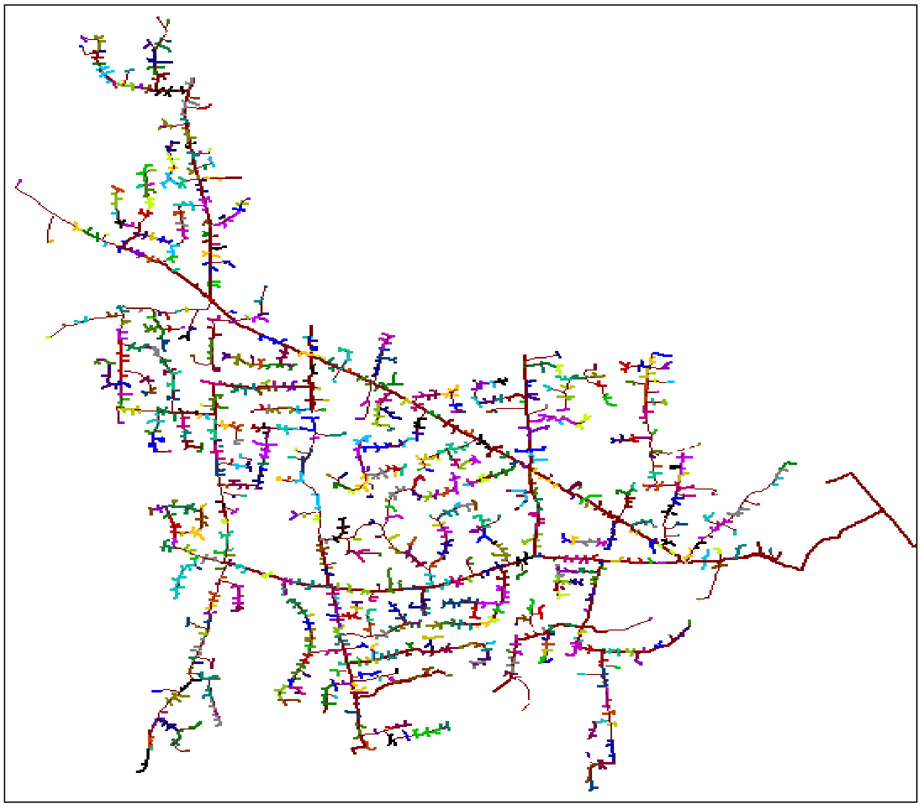


Fig. 3.1-1: One line diagram for residential distribution circuit exported from CymeDist (with number of Devices = 13722, Buses = 6994, Nodes = 13250)

3.1.2 Mixed residential and commercial distribution circuit: mixedCKT

Circuit mixedCKT serves both residential and commercial loads. This distribution circuit contains over 2000 buses serving approximately 4000 customers. The total length of the primary and secondary feeder for the distribution circuit is approximately 50 km.

- The customer loads in the mixedCKT circuit are single-phase, two-phase and three-phase as well.
- The largest load present in the distribution network has a peak demand of approximately 150 kW per phase.
- The daily energy consumption measured at the substation is found to be 70,000 kWh, with approximately balanced demand for the three phases (phase A - 22600 kWh, phase B - 25600 kWh, phase C - 21600 kWh).
- The peak kVA demand recorded at the substation is 5500 kVA.

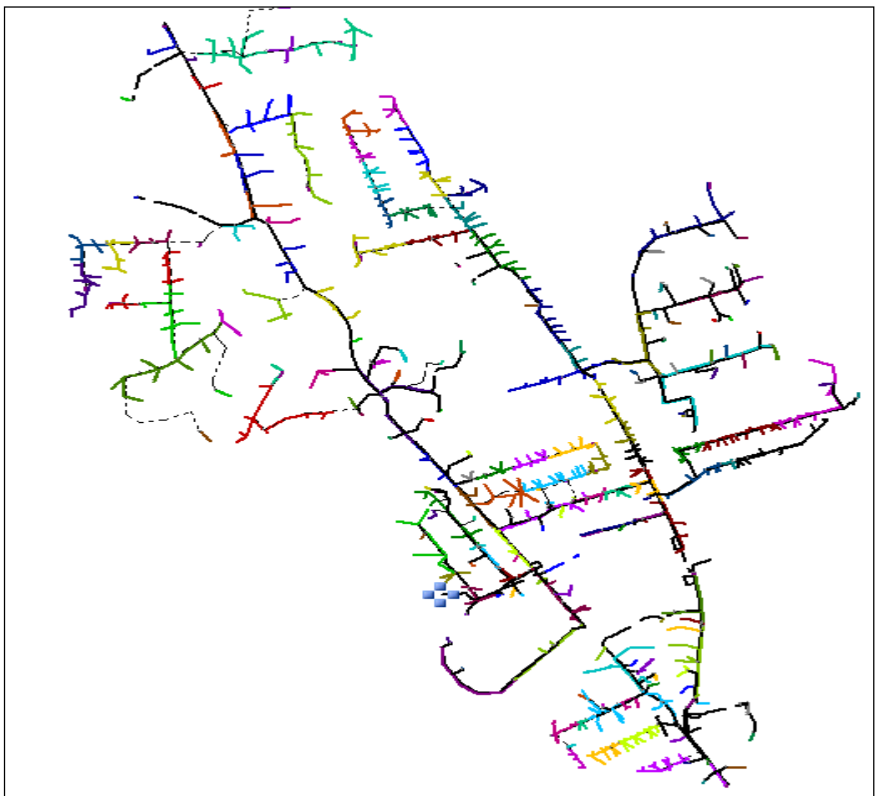


Fig. 3.1-2: One line diagram for the mixed (residential and commercial) circuit exported from CymeDist (with number of Devices = 4055, Buses = 2162, Nodes = 6020)

In this work, various charging scenarios are simulated and the potential factors that could affect the voltage quality of the above mentioned distribution networks are evaluated. Various factors evaluated in this study are:

1. Distance of the service transformer serving the EV charging station from the substation,
2. Location of the EV chargers with respect to the service transformer,
3. Size of the EV charger (240V/16A or 240V/30A) and,
4. Effect of an additional EV charging station added adjacent to an existing EV customer.

3.2 MODEL DEVELOPMENT AND VALIDATION

The voltage variation study is carried out using EPRI's open-source distribution system simulator (OpenDSS) [8]. OpenDSS is a comprehensive electrical power system simulation tool designed primarily for advanced analysis of the distribution systems. It supports nearly all frequency domain (sinusoidal steady-state) analysis commonly performed on the electric utility power distribution systems. Additionally, sequential power flows can be simulated over successive time intervals (e.g., hourly or yearly) for a specified period of time. This capability allows us to perform the daily and yearly load flow analysis for the distribution system with consideration to the variations in EV load patterns and daily and yearly conventional load variations.

The distribution feeder model in CYMDIST is converted to OpenDSS using the method discussed in Chapter 2. The converted model (in OpenDSS) is validated against the CYMDIST model by comparing the solutions for load-flow and short-circuits analysis. The validated electrical model then serves as a base model for which various EV charging scenarios can be simulated and evaluated.

The load flow solutions for CYMDIST and OpenDSS model of the residential distribution feeder are compared in Tables 3.2-1 and 3.2-2. Clearly, the OpenDSS model developed for the distribution circuit agrees with the CYMDIST model.

A comparison for the short-circuit analysis is also drawn for the two models. Detailed comparison is shown in Tables 3.2-3 and 3.3-4. Models agree for the short-circuit analysis as well.

Bus	***CYMDIST (current through the node)***			***OpenDSS (current through the node)***			***Error (%)***
	Phase A (amp)	*Phase B (amp)*	*Phase C (amp)*	*Phase A (amp)*	*Phase B (amp)*	*Phase C (amp)*	
UG_PRI_504	370.7	363.3	397.8	365.6	359.5	392.5	1.25
OH_PRI_104967	1.1	1.5	0	1.1	1.5	0	0
OH_PRI_15733	368.1	360.4	396.2	364.6	358.3	392.5	0.83
OH_PRI_1017258	153	137.9	143.2	151.5	137.2	142.4	0.69
OH_PRI_15017	177.2	158.5	177.8	175.2	157.5	176.3	0.88
OH_PRI_104837	9	6.1	11.4	8.9	6.0	11.0	2.27
OH_PRI_14941	6.7	6.1	11.4	6.6	6.0	11.3	1.24
OH_PRI_1017326	0	17.1	0	0	16.9	0	1.17
OH_PRI_32881	49.8	26.6	27.5	49.2	26.1	27.2	1.35
OH_PRI_1016515	55.2	17.2	46.9	54.5	17.1	46.4	1.09
OH_PRI_108034	7.2	6.8	10.1	7.1	6.8	10.0	0.83
OH_PRI_33723	22.6	10.4	15.6	22.3	10.3	15.4	1.23

Table 3.2-1: Load flow solutions for the primary feeders (residential circuit)

Bus	***CYMDIST (Current Through The Node)***			***OpenDSS (Current Through The Node)***			***Error (%)***
	Phase A (amp)	*Phase B (amp)*	*Phase C (amp)*	*Phase A (amp)*	*Phase B (amp)*	*Phase C (amp)*	
OH_SEC_2252620	21.2	0	0	20.8	0	0	1.9
OH_SEC_2252679	59.9	0	0	59.2	0	0	1.2
OH_SEC_2243162	0	0	65.8	0	0	65.1	1.1
OH_SEC_2242630	0	0	60.9	0	0	60.2	1.1
OH_SEC_2251800	0	71.8	0	0	71.1	0	0.9
OH_SEC_2243253	0	44	0	0	43.6	0	0.9
OH_SEC_2252706	86.1	0	0	85.0	0	0	1.3
SEC_UG_7100	123.2	116.6	114.7	121.8	115.5	113.5	1.0
SEC_UG_476264	95.6	90.5	89	94.5	89.7	88.1	1.0
OH_SEC_2251927	0	0	84.7	0	0	83.8	1.1
SEC_UG_7271	17.1	0	0	16.9	0	0	1.2
SEC_UG_2952	391.5	373	365.5	385.8	368.2	360.5	1.4

Table 3.2-2: Load flow solutions for the secondary feeders (residential circuit)

Fault Bus	***Fault type***	***CYMDIST (Current Through The Node)***			***OpenDSS (Current Through The Node)***			***Error (%)***
		Phase A (amp)	*Phase B (amp)*	*Phase C (amp)*	*Phase A (amp)*	*Phase B (amp)*	*Phase C (amp)*	
936314.086_684060.675	LLL	16412.1	16411.6	16415.9	16576.8	16576.8	16576.9	1.0
936113.741_683989.65	LLL	16720.2	16719.6	16724.1	16888.1	16888.1	16888.1	1.0
932715.582_681443.185	LLL	8210.9	8210.0	8210.1	8291.4	8291.0	8291.44	1.0
1692_444493	LG-B	0	3479.4	0	0	3546.9	0	1.9
931519.462_682604.035	LLL	6678.4	6677.6	6676.4	6759.3	6759.2	6757.6	1.2
929260.444_681636.406	LLL	5331.3	5329.7	5326.4	5404.6	5403.5	5399.4	1.4
929154.514_684418.927	LLL	4983.5	4982.2	4980.2	5056.9	5058.5	5053.8	1.5
924400.858_680661.899	LLL	3601.0	3600.3	3594.1	3668.8	3668.8	3661.5	1.9
921746.25_686147.859	LLL	1130.9	1128.1	1129.2	1176.5	1172.4	1173.8	3.9
921655.45_689810.33	LLL	2730.8	2733.4	2724.7	2786.0	2789.5	2779.8	2.0
926088.454_686746.721	LLL	3794.0	3795.4	3790.8	3859.5	3861.9	3856.5	1.7
924400.858_680661.899	LLL	3601.1	3600.3	3594.1	3668.8	3668.8	3661.5	1.9

Table 3.2-3: Short-circuit analysis for the primary feeders (residential circuit)

Fault Bus	***Fault type***	***CYMDIST (Current Through The Node)***			***OpenDSS (Current Through The Node)***			***Error (%)***
		Phase A (amp)	*Phase B (amp)*	*Phase C (amp)*	*Phase A (amp)*	*Phase B (amp)*	*Phase C (amp)*	
932846.552_681540.8	LG-B	0	1138.3	0	0	1171.5	0	2.9
932457.488_683167.85	LG-C	0	0	2606.3	0	0	2686.8	3.0
932564.537_683515.297	LG-C	0	0	2454.5	0	0	2527.4	2.9
930584.901_682117.422	LG-A	1786.6	0	0	1847.9	0	0	3.4
931105.935_682287.444	LG-A	2616.0	0	0	2700.2	0	0	3.2
925826.723_678445.218	LG-C	0	0	4173.7	0	0	4312.8	3.3
921362.333_678617.701	LG-A	2271.0	0	0	2355.8	0	0	3.7
920965.206_683209.242	LG-B	0	1873.7	0	0	1943.1	0	3.70
920980.202_692251.937	LG-A	1580.1	0	0	1651.1	0	0	4.4
920522.332_686238.657	LG-B	0	1803.3	0	0	1875.1	0	3.9
925652.309_688118.909	LG-C	0	0	1650.2	0	0	1717.5	4.0
926479.719_675915.116	LG-A	1226.6	0	0	1274.6	0	0	3.9

Table 3.2-4: Short-circuit analysis for the secondary feeders (residential circuit)

3.3 LOAD SHAPES FOR CONVENTIONAL LOADS

The previous year's (Year 2011) power consumption data (measured at the substation) and the stratified pricing rate information are used to generate daily load shapes for each secondary distribution load. A daily load shape curve is generated for each stratified load type by averaging their hourly load demand over the year. The strata boundary information is then used to recognize the load type and assign an appropriate load shape based on the monthly kWh demand. In this way the daily load shape is populated for all secondary distribution loads. The section below describes various billing rates defined for the customers served by distribution network under evaluation. Separate billing rates [6] are defined for residential and commercial/industrial customers. Each billing rate is further stratified based on the permissible monthly kWh demand as allowed by the utility.

3.3.1 General Service Rate GS

This billing rate is applied to the commercial/industrial customers. Service under this rate is for all requirements on a customer's premises, provided the customer's demand does not exceed 500 kW in two consecutive months [6]. The rate is further stratified in accordance with the monthly kWh requirement as specified in Table 3.3-1. The load shape generated for the customers served by this billing rate is shown in Fig. 3.3-1. The peak load is observed at around noon as expected for an industrial load.

Strata	Monthly kWh from	Monthly kWh to
GS_1	0	500
GS_2	501	1560
GS_3	1561	4000
GS_4	4001	8400
GS_5	8401	18000
GS_6	18000	Greater

Table 3.3-1: Strata Boundaries for Rate GS

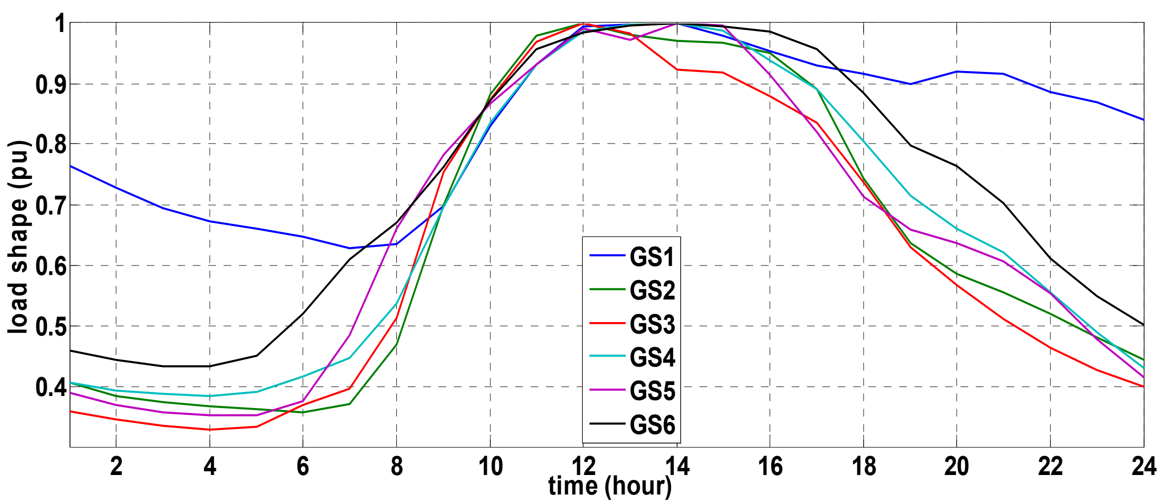


Fig. 3.3-1: Load shapes for stratified Rate GS

3.3.2 General Service Time-of- Day Rate GST

This billing rate is also applied to the commercial/industrial customers. Service under this rate is optional for all requirements on a Customer's Premises, subject to the availability and installation of metering equipment [6]. It is further stratified based on the monthly kWh consumption as specified in Table 3.3-2. The load shape profile shown in Fig.3.3-2 shows the peak demand at noon.

Strata	Monthly kWh from	Monthly kWh to
GST_1	0	15000
GST_2	15001	50000
GST_3	50001	100000
GST_4	100001	Greater

Table 3.3-2: Strata Boundaries for Rate GST

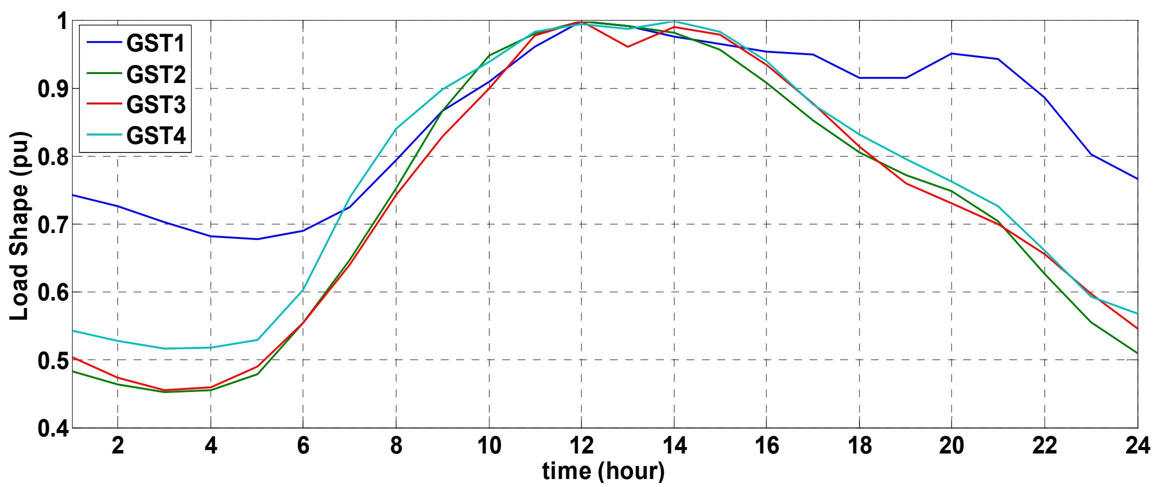


Fig. 3.3-2: Load shapes for stratified Rate GST

3.3.3 Large Power Time-of- Day Rate LPT

As the name suggests this billing rate is applied to the industrial customers with large monthly kWh demand.that cannot be covered by GS and GST. As expected the service under this rate is optional for the customers [6]. The stratified pricing boundaries are specified is Table 3.3-3. The load shape profiles for the customers served by LPT rate are generated and shown in Fig.3.3-3. As expected for an industrial load the peak demand is observed at noon.

Strata	Monthly kWh from	Monthly kWh to
LPT_1	0	102000
LPT_2	102001	223980
LPT_3	223980	AND GREATER

Table 3.3-3: Strata Boundaries for Rate LPT

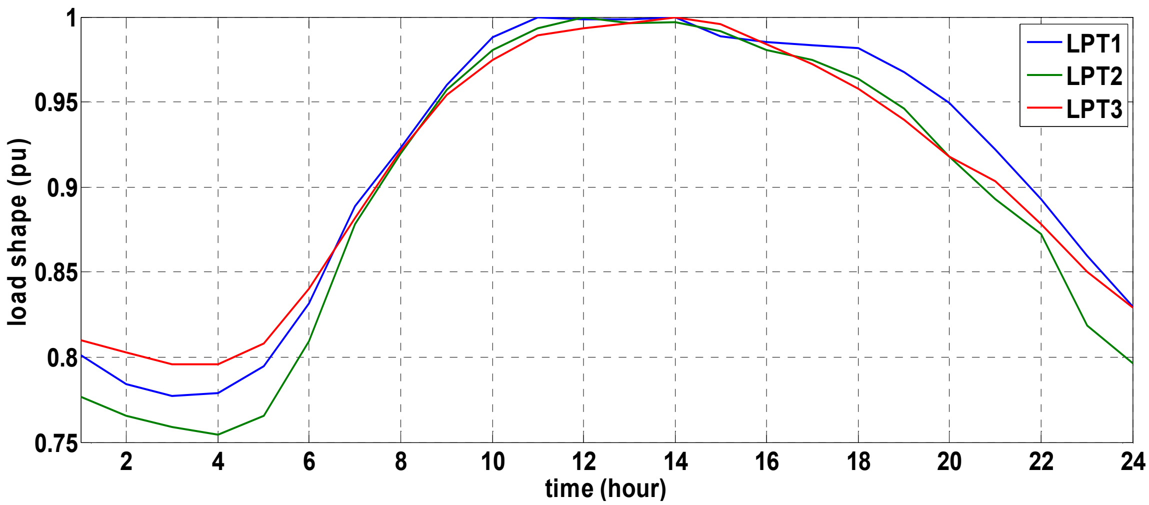


Fig. 3.3-3: Load shapes for stratified Rate LPT

3.3.4 Residential Rate R

Service under this rate is for all normal residential requirements and qualifying veterans organizations, agricultural, campground and marina usage [6]. Table 3.3.4 shows the stratified monthly kWh consumption for this rate. Clearly monthly kWh demand required by residential customers served under this rate cannot exceed more than 2000 kWh. The load shape profile shown in Fig.3.3-4 observes the peak demand at around 8 PM, characterizing the residential load characteristics.

Strata	Monthly kWh from	Monthly kWh to
R_1	0	500
R_2	501	1000
R_3	1001	1500
R_4	1501	2000

Table 3.3-4: Strata Boundaries for Rate R

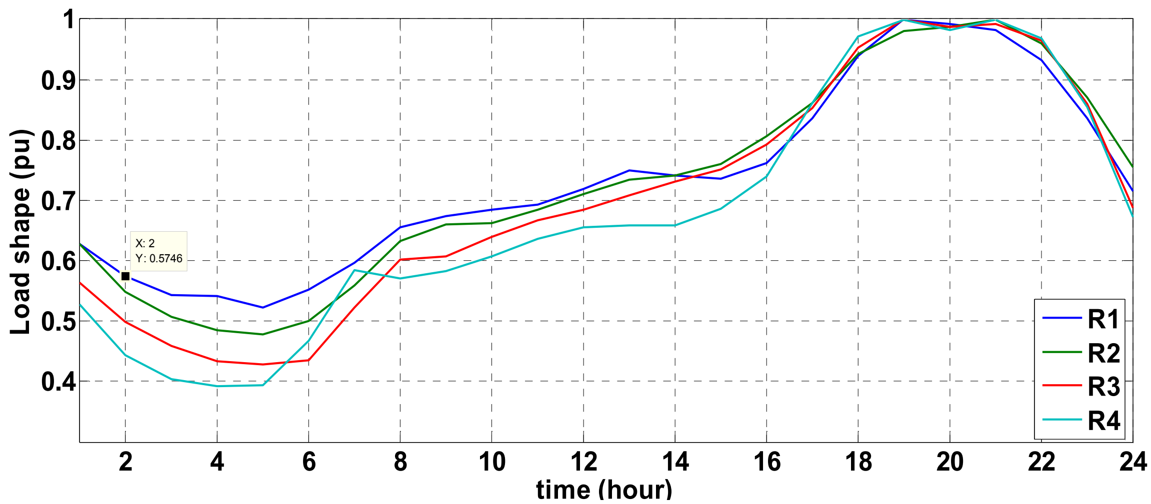


Fig. 3.3-4: Load shapes for stratified Rate R

3.3.5 Residential Time-of- Day Rate RT

Any residential customer that consumes more than 2,000 kWhr in a single monthly is placed on rate RT for billing purposes. Service under this rate is optional for all individually metered residential requirements.

Strata	Monthly kWh from	Monthly kWh to
RT_1	0	750
RT_2	751	1560
RT_3	1561	6000
RT_4	6001	and greater

Table 3.3-5: Strata Boundaries for Rate RT

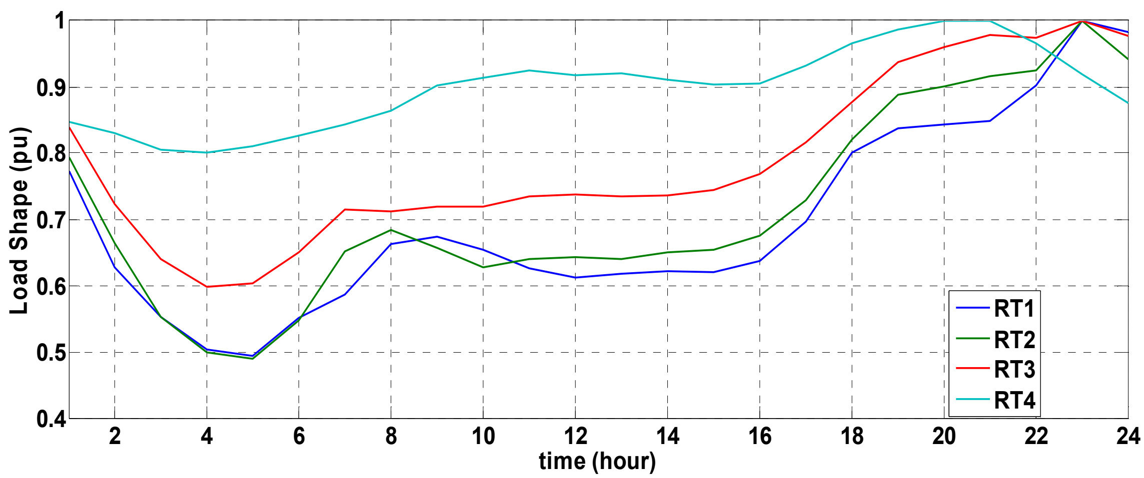


Fig. 3.3.5: Load shapes for stratified Rate RT

Table 3.3-6 is used for assigning load shapes to the secondary distribution loads. In cases where multiple load shapes could be assigned to a load, the most appropriate load shape (shown in bold) is assigned to the customer. The rationale behind assigning a particular load shape to the customer in the case of conflict in the strata boundary is also discussed in Table 3.3-6.

Monthly kWh demand		Daily Load Shapes that could be used	Reason for choosing a particular load shape
kWh from	kWh to		
0	500	R1, **GS1**	GS1 assuming the loads represent small shops with peak load at noon.
501	1000	**R2,** GS2, RT1	R1 and RT1 have similar load shape. R2 as representative load shape assuming they represent household loads with peak load from 6 pm to 12 am
1001	1500	RT2, **R3**	Approximately similar load profile, hence choice doesn't matter
1501	2000	R4	
2001	6000	GS3, **RT3**	Per unit load demand for GS3 is less than RT3.
6001	8400	GS4	
8401	10000	GST1	
10001	18000	**GS5,** RT4,	More power demand by GS5 strata
18001	50000	GS6, **GST2**	Both have similar profiles. Larger per unit power demand for GST2, prompted to choose GST2.
50001	100000	GST3,**LPT1**	Both have similar profiles. Larger per unit power demand for LPT1, prompted to choose LPT1
102001	223980	**LPT2**,GST4	Both have similar profiles. Larger per unit power demand for LPT2, prompted to choose LPT2
223981	and greater	LPT3	

Table 3.3-6: Assigned Load Shape Profile

Chapter 4: EV Charger Characteristics

The detailed models of the EV chargers based on their switching dynamics are not required for the voltage quality evaluations. The voltage variation in the distribution feeder (recoded for a day) is a steady-state event; hence a steady state model for the charging stations will be more appropriate. Field measurements taken at the EV charging facility suggest a constant power profile for the EV loads. Also the commercial charging circuits are equipped with advanced controls, designed to draw constant current while maintaining a constant charging voltage. Hence for the voltage quality evaluations, the EV charging stations are modeled as a constant power load with an associated daily load shape profile. The load shape profile for an EV charging station is generated based on the type of EV battery, the vehicle traffic and the type of secondary load (residential or commercial faculty) to which the EV charging station is connected.

4.1 Charger Specifications

Since EVs directly use electric energy for propulsion, they need to be charged on a regular basis. Specifications for EV charging stations are standardized by the Society of Automotive Engineers. SAE J1772™ [9] is a North American standard for the electrical connectors for EVs. The formal title of this standard is "SAE Surface Vehicle Recommended Practice J1772”.

SAE J1772™ identifies three levels of charging based on the voltage and power levels, as shown in Table 4.1-1.

Type	Power Level
Level -1: 120V (AC)	1.2 – 2.0 kW
Level -2 (low): 208-240V (AC)	2.8 - 3.8 kW
Level-2 (high): 208-240V (AC)	6 – 15 kW
Level- 3: 208-240V (AC)	>15 kW-96 kW
Level -3: DC Charging: 600V (DC)	>15 kW-240 kW

Table 4.1-1: EV charger specifications

The EV load charging profile influences the voltage quality of the distribution system as it partially defines the daily load shape profile seen by the service transformer. The load shape or the charging profile generated for an EV is defined by the EV's battery size, charger efficiency, the batteries' state of charge, and the type of charging facility. An example of how charge profiles vary over time for an 8-kWh battery [10] (for an EV with 0% remaining charge) is provided in Fig. 4.1-1.

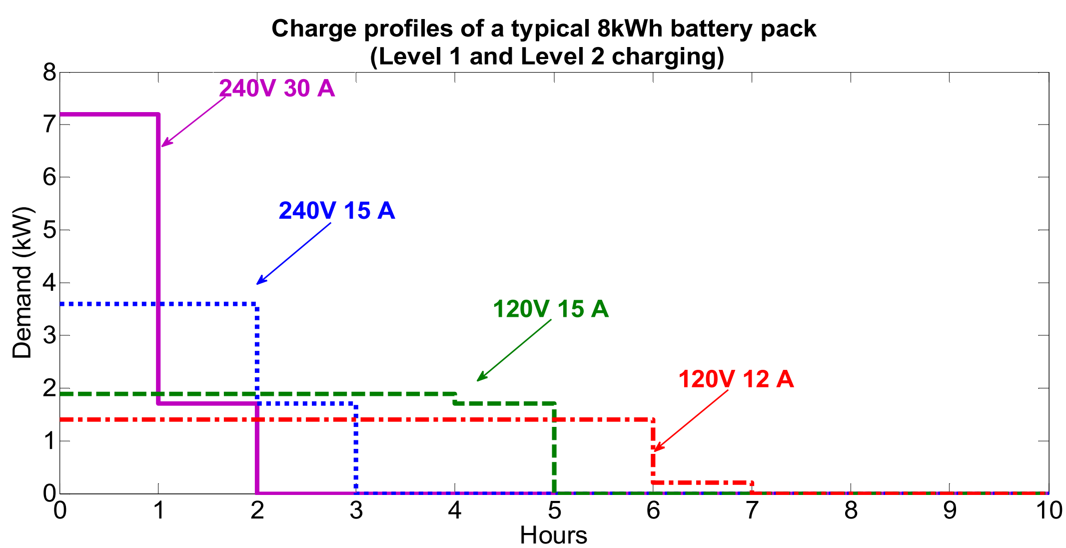


Fig. 4.1-1: Load shape profile for 8 kWh EV battery.

The electrical demand over time for an EV load is clearly not constant for all time. In a battery charger, the charge remains constant until the state of charge (SOC) of the battery reaches +90%. After which, the rate of charge is decreased until the battery is fully charged. The configuration of the shapes in the Fig. 4.1-1 are general approximation of this charging scheme; given the inaccuracy associated with an hourly time step and desire to match the kWh.

Herein the potential impacts of the commercial charging stations having a voltage rating of 240 V are evaluated. The study has been performed for Level-2 (low) charger with rating 240V/16A and Level-2 (high) with rating 240V/30A. Two different electric vehicles having the following battery sizes are considered:

1. Chevrolet Volt (16-kWh) [11] and
2. Nissan Leaf (24-kWh) [12]

The charging profiles for the 16-kWh and 24-kWh batteries are generated based on the charging profiles for an 8-kWh battery (Fig. 4.1-1). A 16-kWh battery takes three hours to charge using a Level-2 (high) charger and five hours using a Level-2 (low) charger as shown in Fig.4.1-2.

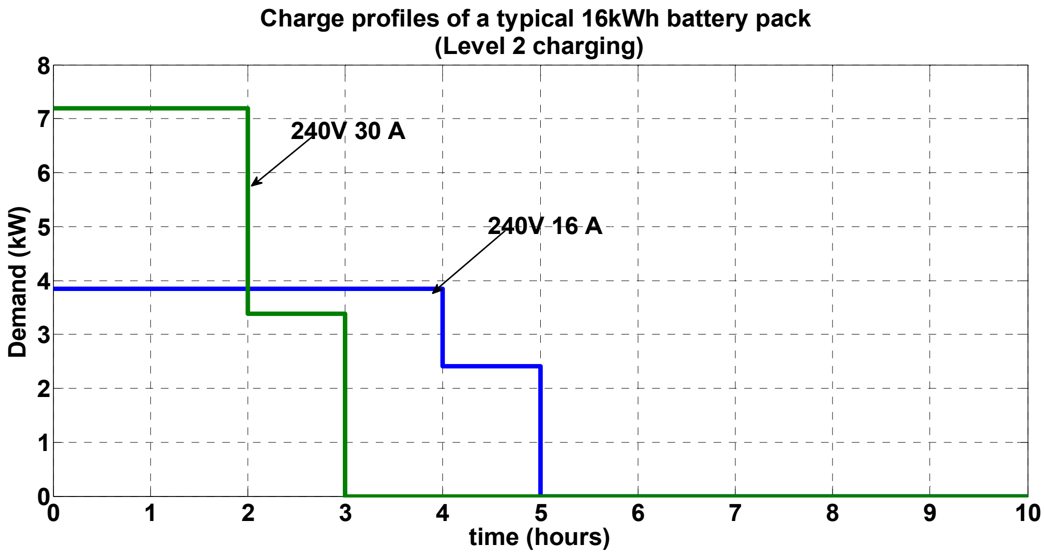


Fig. 4.1-2: Load shape profile for 16 kWh EV battery (Level-2 charging).

The 24-kWh battery takes approximately 5 hours to fully charge from 0% state of charge(SOC) using a Level-2 (high) charger and 8 hours using a Level-2 (low) charger (Fig.4.1-3).

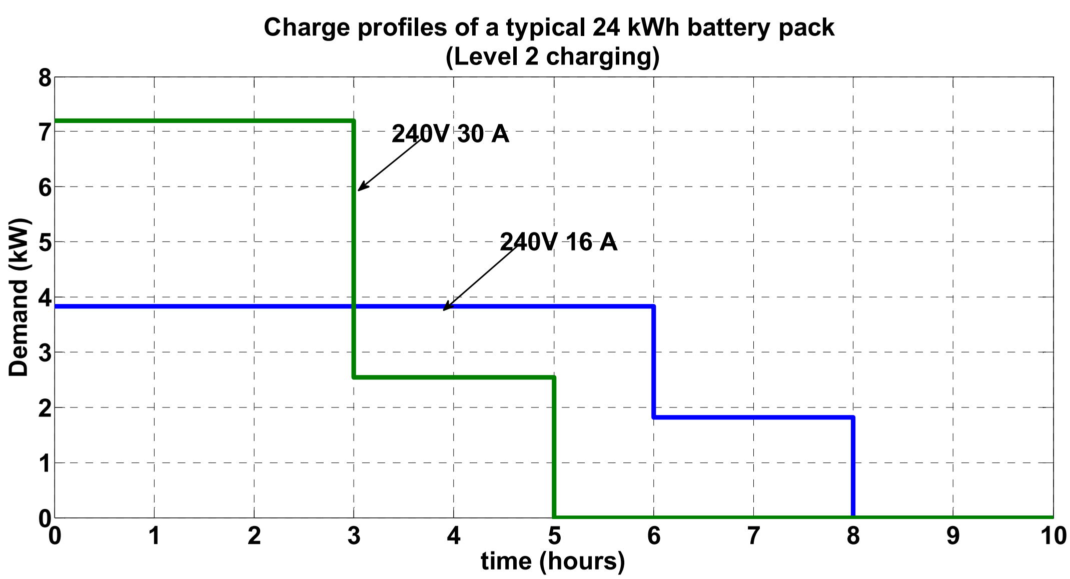


Fig.4.1-3: Load shape profile for 24 kWh EV battery (Level-2 charging).

4.2 VALIDATION OF THE EV LOAD MODEL USING FIELD MEASUREMENTS FOR THE EV CHARGING STATIONS

Real time measurements are taken at a charging facility using Fluke-434 power quality analyzer [13]. The secondary network power quality during EV charging is recorded. The measurements include; secondary voltage profile, secondary current profile, current harmonics, voltage harmonics and power demand curve. The charging facility is populated with four CT500 (ChargePoint® Networked) [14] charging stations. The one-line diagram for the secondary network chosen for the measurements is shown in Fig 4.2-1.

The CT500 charging station is a 7.2 kW single output station designed for single and multi-family homes, apartments and condominium buildings, and light commercial and fleet applications for the North American marketplace. The station delivers Level-2 (208/240 V @ 30 A) charging and is compatible with plug-in electric vehicles that comply with the SAE J1772™ plug-in electric vehicle charging standard.

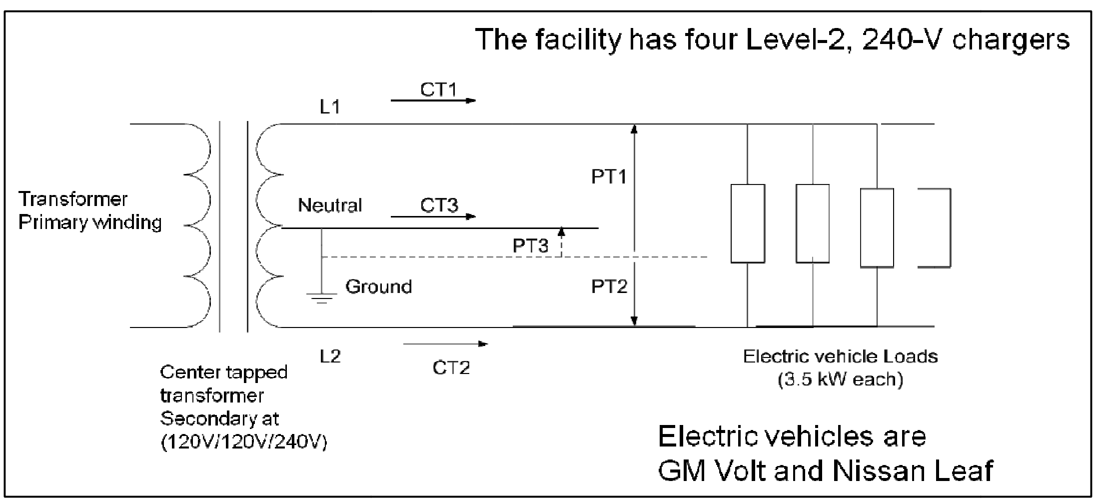


Fig.4.2-1: One-line diagram of the secondary network under evaluation

The power trend measured by the power quality meter is shown in Fig. 4.2-2. It can be seen that the power demand remains constant while the EV load is charging. The constant power demand justifies a constant power model for the EV load. Although the charging station can deliver 7.2 kW, the load demand for each EV battery under consideration is only 3.5 kW. This is attributed to the fact that the charging current is limited to16A by the EV. Table 4.2-1 summarizes the power demand by the EV loads for the measurement time interval.

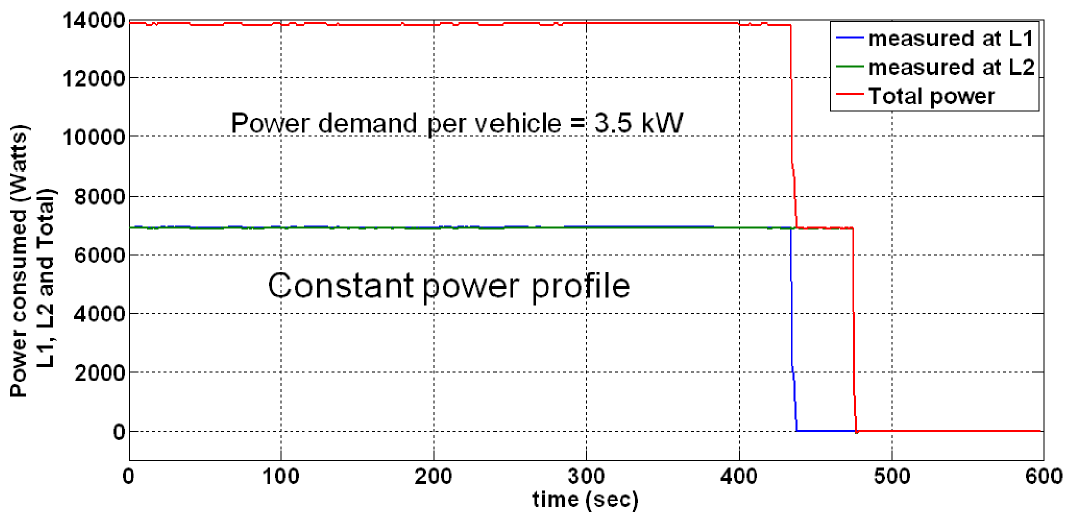


Fig.4.2-2: Power demand measured at the secondary network

t< 420 sec	**420 < t < 470**	**t> 470 sec**
kW (L1) = 6.93 kW kW (L2) = 6.91 kW Total power = 13.84 kW EV loads = 4	kW (L1) = 0 kW kW (L2) = 6.91 kW Total power = 6.9 kW EV loads = 2	kW (L1) = 0 kW kW (L2) = 0 kW Total power d = 0 kW EV loads = 0

Table 4.2-1: Power demand at the secondary network

4.3 ESTABLISHING LOAD SHAPE PROFILES FOR EV CHARGING STATIONS

The EV charging stations are modeled as a conventional constant power load with an associated load shape curve. The load shape defines hourly load profile for the EV charging stations. The daily variations in EV and conventional load shapes are captured by running load flow analysis for a day, in an interval of an hour. This is referred as 'daily load flow analysis'. Using the daily load flow analysis, daily and seasonal variation in the conventional load can be captured. The load shape for an EV charging station depends on numerous factors .The specific factors considered in this study for defining the EV load shape profile are as follows.

4.3.1 Size of the EV charging station (240V/16A or 240V/30A)

The charging profile of an EV load will depend upon its power rating. A charging station of type 240V/16A with power level of 3.84 kW takes more time to charge an EV battery as compared to a 240V/30A (power level 7.2 kW). Therefore, it is required to simulate the load profile for both types of EV chargers. The charging profiles for both types of the EV chargers are simulated (using Fig 4.1-2 and Fig 4.1-3) and are used in accordance with the evaluation case.

4.3.2 Battery size of the incoming vehicle

Mainly two types of batteries are considered in this study: Chevy Volt (16-kWh) and Nissan Leaf (24-kWh). Using the charging profile for a Level-2 charger (Fig. 4.1-2 and Fig. 4.1-3) for both types of batteries, load shape for a particular EV load is simulated.

4.3.3 Vehicle traffic for the day (e.g. weekday/weekend)

The vehicle traffic information is captured in the load shape profile by randomizing the time delay between two cars arriving at the charging facility. For the case with low traffic (weekends), the time delay between cars is increased to represent that the charging facility is underused. And during the days with heavy traffic (weekdays), the time delay between cars getting served by the charging facility is kept minimum. This information is used to generate yearly load shape profile, which could be used in future work to do yearly simulations for the stochastic impact of EV loads on the distribution networks.

4.3.4 Type of charging facility

Time of utilization of the charging facility is correlated to the type of secondary loads served by the secondary network under evaluation. The probabilistic time of charging could be decided based on the characteristics of the secondary load. For instance if the charging facility is serving a residential load (having peak load between 6 pm to 12 am), the charging facility is expected to be at maximum utilization after the residents get back to home, i.e. from 6 pm to 8 am. On the other hand if the charging facility is serving a commercial load then the expected hours of operation of the EV station would be from 8 am to 6 pm. EV load shapes are generated based on the type of the secondary loads to which the charging facility is connected.

It should be noted that the controlled charging of the EV loads is not considered in this work. Therefore, charging could take place during hours of peak demand and service transformers could get overloaded.

4.3.5 State of charge of incoming vehicle

It is assumed that the vehicle coming to the charging facility could have state-of charge (SOC) in a range of 20% to 60%.To simulate a more realistic scenario SOC of incoming vehicle is randomized. Also the owner of the car might not wait for vehicle to get 100% charged. Hence stop time of the charging is also randomized. It is assumed that the owner could disconnect the car while SOC is anywhere in between 85% to 100%. Thus random incoming and outgoing SOC parameters of the vehicle randomize the charging time for each vehicle.

4.4 EV LOAD PROFILES FOR VARIOUS CHARGING CONDITIONS

Based on the factors mentioned above, two example load shapes are generated in this section. Example 1 presents the charging station installed at a commercial load location and active during the normal office hours, i.e. from 8 am to 6 pm. Example 2 demonstrates a charging station located at a residential facility active from 6 pm to 8 am.

4.4.1 Load shape for an EV charging station located at a commercial facility

An example EV load shape for an EV load connected to a commercial facility with time of operation from 8 am to 6 pm is shown in Fig 4.4-1. Details of this EV charging station are as follows:

- Charging station type: 240V/30A (7.2 kW)
- Battery specification: 16-kWh
- Vehicle traffic for the day
    - Maximum traffic for the day
    - Time delay between two cars less 10 min
- Charging facility : university, hospital or business complex
    - Operation time for the charging station is 8 am to 6 pm
- State of charge of incoming vehicle : [20% to 60%]

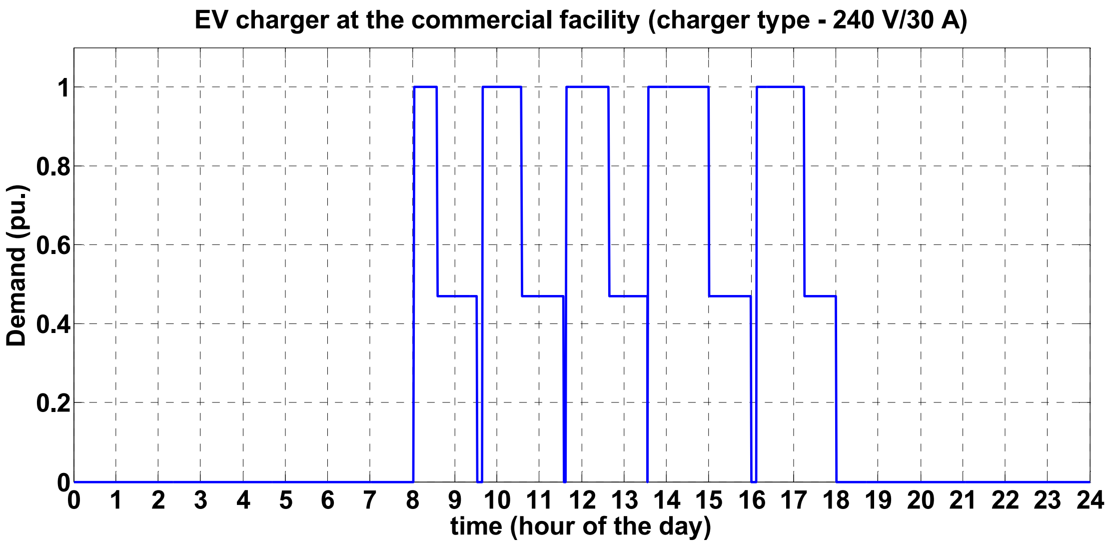


Fig. 4.4-1: An example EV charging station load shape profile located at a commercial facility (Number of cars served in a day: five)

Fig. 4.4.1 shows that five EVs are getting charged at the respective charging station in a day. The explanation of the charging profile for the first EV (charged from 8 am to 9:30 am) is discussed here. The state of charge (SOC) of the incoming vehicle is 57%, which is obtained by getting a random number between 20% and 60%. The EV is charged at a rate of 7.2 kW/hr until its SOC reaches 81%. After that the EV is charged at 3.37 kW/hr until it is fully charged. It is then disconnected and a new vehicle is connected to the charger.

4.4.2 Load shape for an EV charging station located at a residential facility

Another example EV load shape for a different EV charging station is shown is Fig 4.4-2. This EV charging station is serving a residential facility having EV charging demand from 6 pm to 8 am. Details of the charging station are as follows:

- Charging station type: 240V/16A (3.84 kW)
- Battery specification: 16-kWh

- Vehicle traffic for the day
    - o Maximum traffic for the day
    - o Time delay between two cars less 10 min
- Charging facility : residential customer
    - o Operation time for the charging station is 6 pm to 8 am
    - o This time interval is also the period for peak demand for a residential customer; hence service transformer could be overloaded.
- State of charge of incoming vehicle : [20% to 60%]

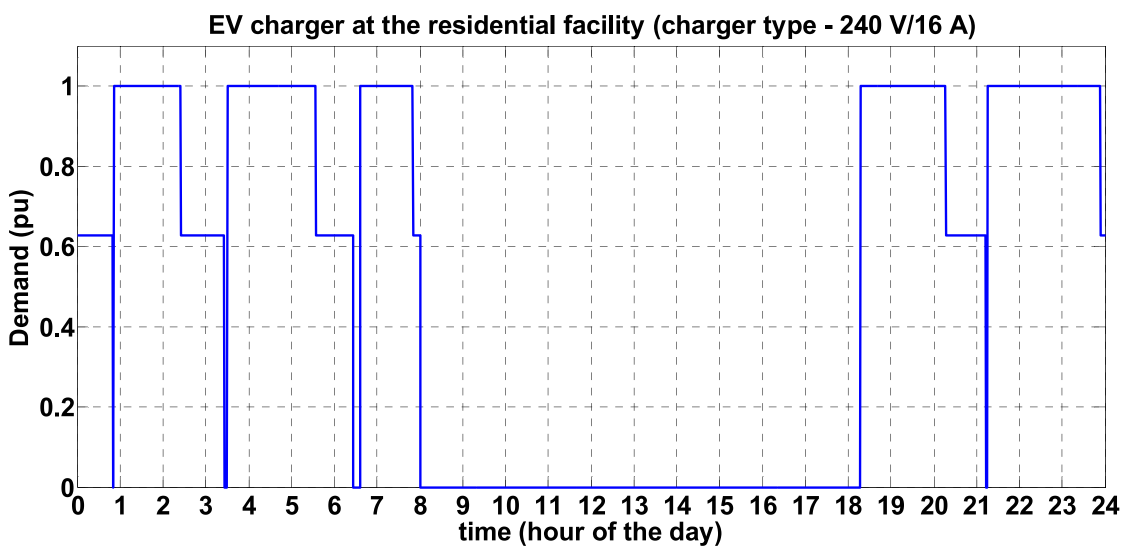


Fig. 4.4-2: An example EV charging station load shape profile located at a residential facility (Number of cars being served in a day : five)

It should be noted that the above charge profile (Fig. 4.4-2) for the EV charging station connected to a residential facility suggests that five electric vehicles are getting charged by the charging station per day. This is not a typical behavior for a residential electric vehicle charger. It is impractical to assume that a house owns five electric vehicles. However, above charging profile is assumed so that the impact analysis of the

EV chargers could be extended to a multi-family residential facility, such as an apartment complex. In case of an apartment complex multiple owners could own electric vehicle and hence the charging scenario becomes clearer.

Also, assuming the charging profile shown in Fig. 4.4-2 for a house (with single owner) doesn't affect the maximum voltage drop seen by the secondary distribution customer. Since, the EVs are getting charged sequentially hence, at a time only one EV affects the voltage profile and hence the maximum voltage drop. Therefore, along with representing a charging station connected to a house, the charging profile shown in Fig. 4.4-2 generalizes the impact of an EV charger connected to a multi-family residential facility. Similar assumptions are made for the EV charging stations connected to a residential facility for various charging scenarios discussed in Chapter 5 and Chapter 7.

Chapter 5: Evaluation of voltage variations on the secondary networks supplied by a single-phase service transformer

The objective of this chapter is to evaluate and compare various factors that affect the voltage variations in the secondary network during EV load charging. Various charging scenarios are analyzed and simulated by varying the circuit evaluation parameters shown in Table 5.1-1.

General evaluation procedure is described as follows. A single-phase distribution transformer with typical kVA rating of 15 kVA to 50 kVA is selected for the study. The secondary network served by the service transformer is supplying for 4 to 8 conventional loads. EV charging stations are populated according to the conditions specified for a particular case study and the percentage voltage drop in the secondary network is recorded. The different case studies are compared for their effects on the voltage profile of the secondary network. The specific factors evaluated in this chapter are as follows:

1. Distance of the service transformer from the substation,
2. Location of the EV chargers with respect to the service transformer,
3. Size of EV charger (240V/16A or 240V/30A) and,
4. Effect of additional EV charging station added adjacent to an existing EV load.

Herein, for both distribution feeders, voltage quality evaluation is done only for the residential customers. As mentioned in Chapter 4, for residential customers, the EV charging station connected a secondary load node is assumed to be charging multiple electric vehicles sequentially. Assuming an uncontrolled charging case, the most convenient time for the residential customers to utilize the charging facility will be from 6 pm to 8 am. Hence, for all charging scenarios evaluated below, a voltage drop on the secondary network is recorded from 6 pm to 8 am. The EV charging effects for the commercial loads in a mixed distribution feeder are evaluated in chapter 6.

5.1 ANALYTICAL APPROACH

The evaluation conducted herein considers two distribution circuits, one with only residential loads and the other with both residential and commercial loads. The distribution circuit models, commercial EV charger models and likely customer behaviors are used to construct the distribution system electrical model. Various factors that could potentially affect the voltage profile of the secondary network are characterized and used to simulate multiple charging scenarios. For each charging scenario, a daily load flow analysis is done using the distribution system electrical model and the load shapes for conventional and EV loads. The simulated charging scenarios are then evaluated and compared for their impact on the voltage profile of the distribution network. Fig. 5.1-1 summarizes the proposed analysis approach.

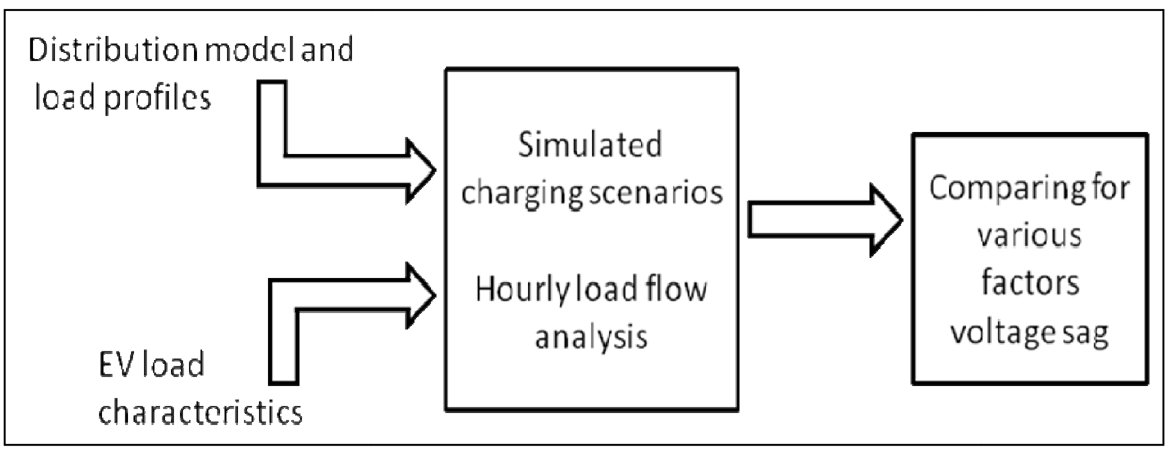


Fig. 5.1-1: Proposed analysis approach

Table 5.1-1 summarizes various charging scenarios discussed in this section. Every charging scenario is conducted for the two types of distribution feeders, residential and mixed.

Section number	Circuit parameters under evaluation	Different conditions evaluated for	Condition for the largest voltage drop
Section 5.2	Location of the service transformer w.r.t. the substation	Remote from the substation	Service transformer remote from the substation
		Nearby the substation	
Section 5.3	Location of the EV charging station w.r.t. the service transformer	Remote from the service transformer	EV load remote from the service transformer
		Nearby the service transformer	
Section 5.4	Size of the EV charging station	240V/16A	EV load of type 240V/30A
		240V/30A	
Section 5.5	Additional EV load added adjacent to the existing EV load	One EV load	Additional EV load increases the voltage drop
		One+One EV load	

Table 5.1-1: Various factors evaluated for impact on the secondary network

5.2 Effects of Location of the Service Transformer with respect to the Substation: Remote vs. Nearby

The objective of this section is to evaluate effects of location of the service transformer with respect to the substation on the voltage variation of the secondary network. Since each service transformer serves a secondary network, the analysis presented below also evaluates the impact of location of the secondary network on its voltage profile, due to EV charging.

For evaluation purpose, two service transformers are chosen for comparison, one remote from the substation and the other nearby the substation. The secondary network under evaluation is assigned one 240V/16A EV charging station at the farthest load node from the service transformer. The evaluation is done for both residential and mixed distribution circuits. Table 5.2-1 summarizes the evaluation conditions.

Evaluation parameters				
Location of service transformer	*Circuit type*	*Charging Station*	*Location of EV w.r.t. the service transformer*	*Number of EVs in the secondary circuit*
Remote vs. Nearby	Residential	240 V/16A	Remote	One
Remote vs. Nearby	Mix	240 V/16A	Remote	One

Table 5.2-1: Parameters to evaluate effects of location of the service transformer

Based on the analysis presented in Section 5.2.1 and 5.2.2, the following observations are made:

- Secondary networks farther out from the substation tend to have lower voltage magnitudes than those nearby the substation. This phenomenon is true for both residential and mixed residential and commercial circuits.
- For both types of circuits, the largest voltage drop occurs when the service transformer is remote from the substation and it is approximately 1.5%.

5.2.1 Effects of location of the service transformer with respect to the substation for a residential circuit

To determine the effects of location of the service transformer on voltage profile of the secondary network, voltage magnitude at each load node during EV load charging is evaluated and compared. For this purpose, two transformers are chosen: one remote from the substation and one nearby. Characteristics of the secondary networks served by these two transformers are summarized below (Table 5.2-2).

Service transformer location	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)	Number and location of EV w.r.t to the service transformer
Remote	37 kVA	8	36.6 kW	40.1 kW (overloading)	One and remote
Nearby	50 kVA	4	15.2 kW	18.7 kW	One and remote

Table 5.2-2: Characteristics of the secondary networks under evaluation

Fig. 5.2-1 shows hourly load demand for the two service transformers (remote/nearby) with and without an EV load. Since the time of operation of the EV charging station is chosen from 6 pm to 8 am, hence an increase of 3.45 kW demand is recorded for that time period only. During this time period the EV charging station is serving multiple EVs sequentially, thus causing an increase in the kW demand. However, since the EVs are charged sequentially, at any instant the maximum increase in kW demand is not more than 3.5 kW (which corresponds to the kW demand for one EV). Transformer overloading during peak demand hours is recorded for the case when the service transformer is remote from the substation. However no such overloading is recorded when the service transformer is nearby the substation.

For both transformer locations, the largest voltage drop in the secondary network (Fig. 5.2-2) is caused by the maximum increase in kW demand. Since maximum increase in kW demand corresponds to the kW demand of one EV, hence assuming multiple EVs getting sequentially charged by the EV charging station does not affect the maximum voltage drop corresponding to one EV load charged by the EV charging station.

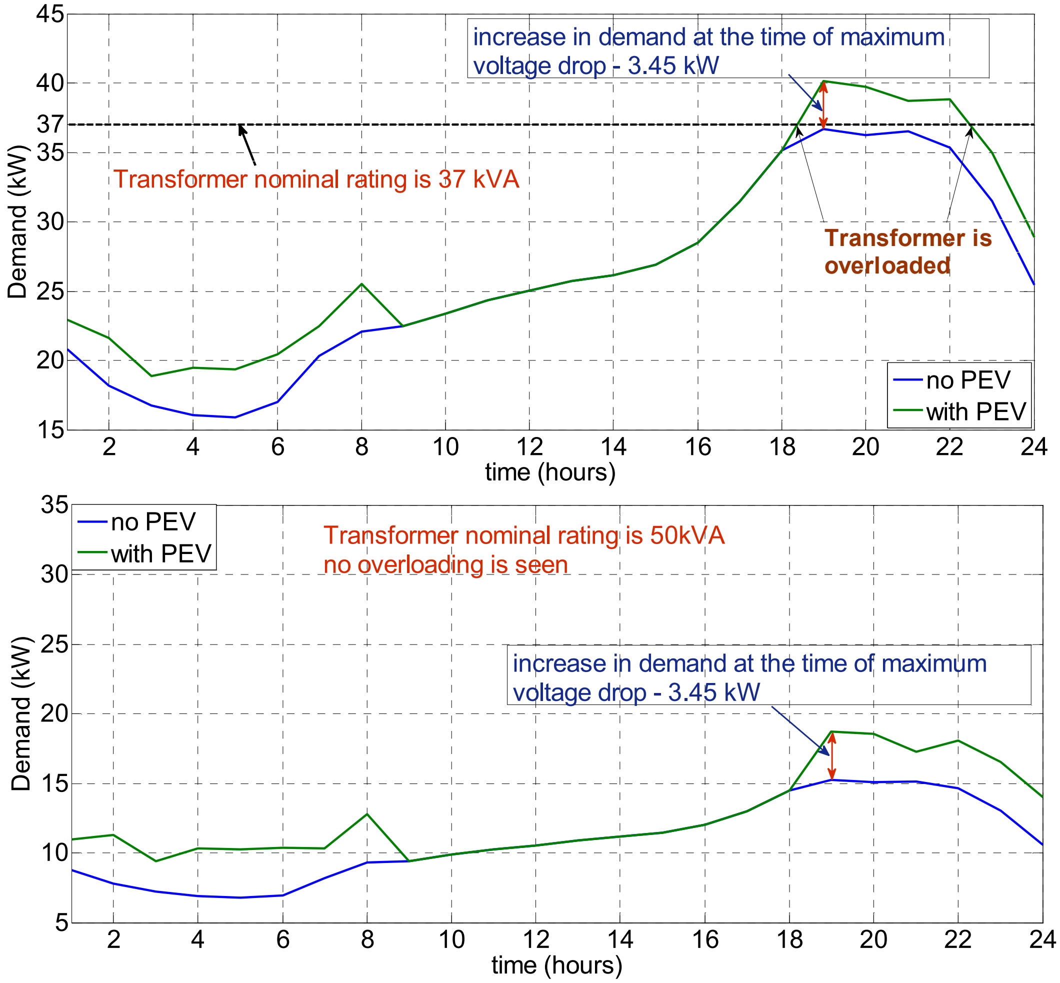


Fig. 5.2-1: Load shape profiles, with and without an EV load for the residential circuit. The service transformer is (a) distant from the substation and (b) nearby the substation.

Fig. 5.2-2 shows the largest voltage variation recorded for the two cases (remote/nearby). During normal operating conditions, the largest voltage drop recorded for remote and nearby service transformers are about 1.5% and 1%, respectively. In either case the largest voltage drop takes place at the load node where the EV load is located.

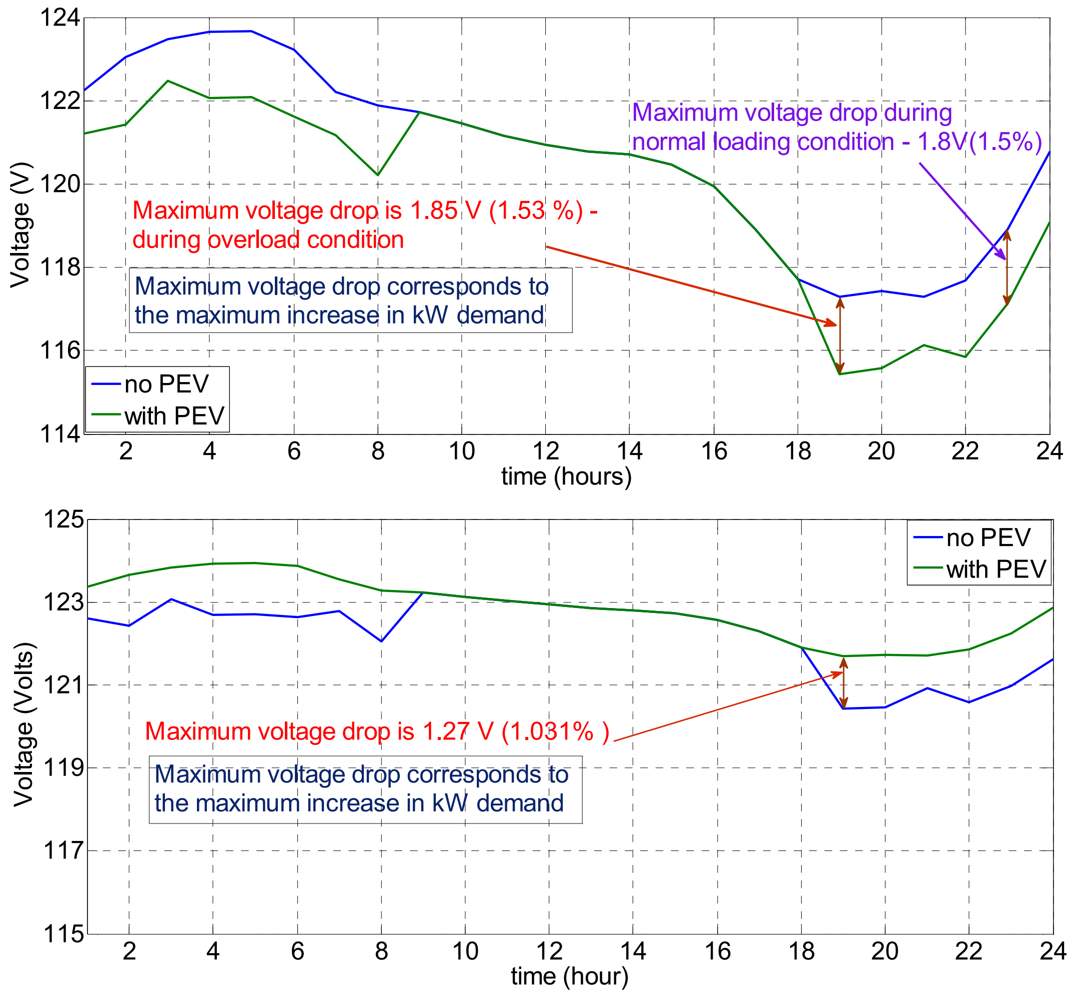


Fig. 5.2-2: Largest voltage drops, with and without an EV load for the residential circuit. The service transformer is (a) distant from the substation and (b) nearby the substation.

Largest voltage drop seen at each load node in the secondary networks under evaluation is shown in Fig. 5.2-3. The location of the EV load is shown in a yellow-shaded rectangle.

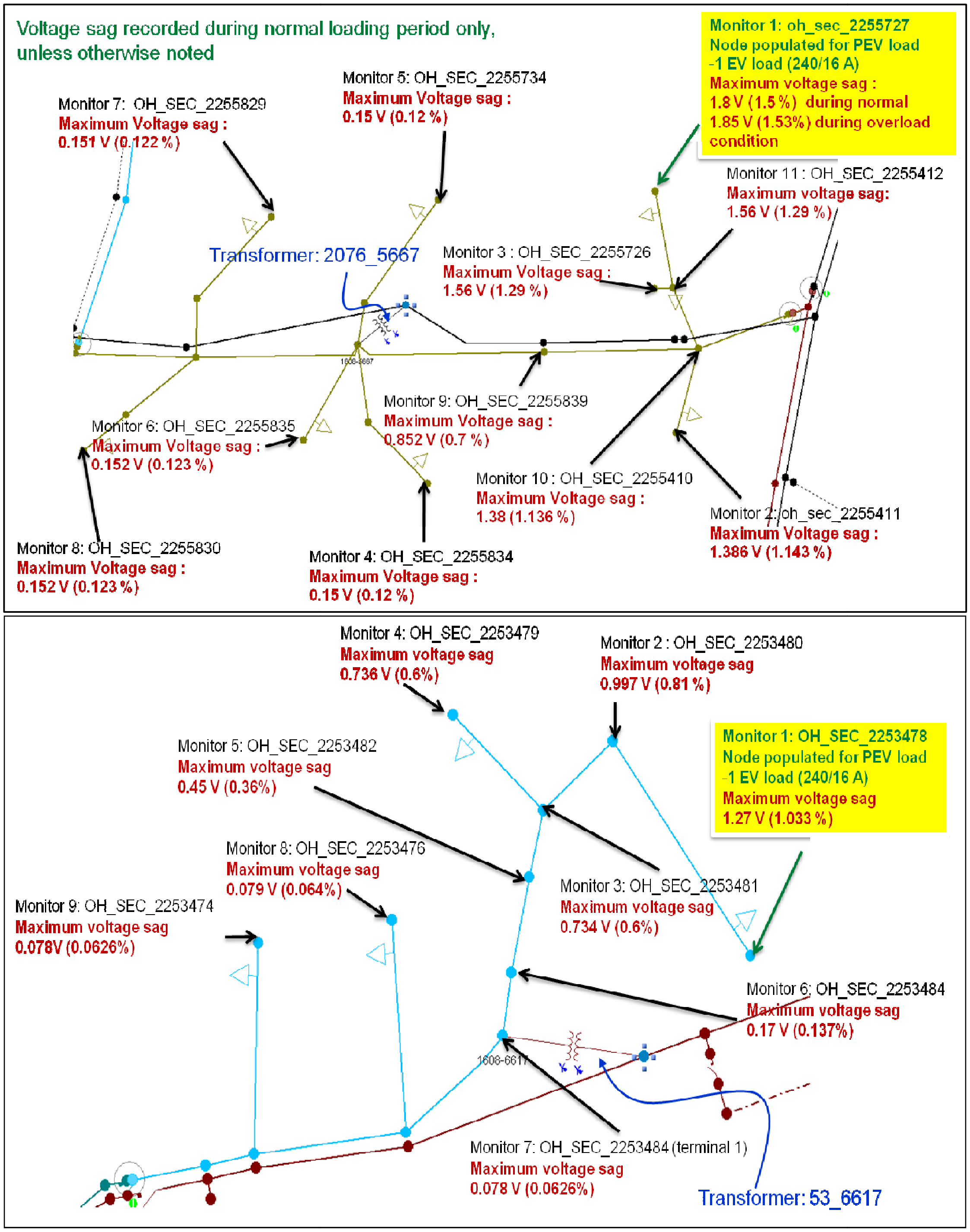


Fig. 5.2-3: Largest voltage drop in each load node during the EV load charging for the residential circuit. The service transformer is (a) remote from the substation and (b) nearby the substation

Comparing the voltage drops in both remote and nearby secondary networks during EV charging, the following observations are made:

- Largest voltage drop takes place at the load node where the EV load is located. Load nodes in the EV charging current path also suffer comparable voltage drops. Load nodes off the charging path are less impacted.
- The remote secondary network suffers larger voltage drops than the nearby secondary network. The magnitude of voltage drop for each network is compared in Table 5.2-3.

Load nodes in the secondary network	**Transformer remote from the substation**	**Transformer nearby to the substation**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.5%) During overload - 1.85 (1.53%)	1.27 V (1.03%)
Load nodes without EV, but in the EV charging current path	1.56 V (1.3%)	1 V (0.81%)
Other non-EV load nodes	0.15 V (0.122%)	0.079 V (0.064%)

Table 5.2-3: Effects of location of the service transformer with respect to the substation for a residential circuit

5.2.2 Effects of location of the service transformer with respect to the substation for a mixed residential and commercial circuit

A similar analysis is done for a mixed distribution circuit, which consists of both residential and commercial loads. Two transformers are chosen: one remote from the substation and one nearby. It should be noted that both the transformers chosen for the analysis are serving residential loads. A separate analysis in chapter 6 is done for the secondary networks serving commercial loads. The characteristics of the secondary networks served by these two transformers are summarized below.

Service transformer location	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)	Number and location of EV w.r.t to the service transformer
Remote	25 kVA	6	9.4 kW	12.8 kW	One and remote
Nearby	25 kVA	6	8.7 kW	12.1 kW	One and remote

Table 5.2-4: Characteristics of the secondary networks under evaluation

Fig. 5.2-4 shows hourly load demand for the two service transformers (remote/nearby) with and without an EV load. The increase in demand is recorded when the EV load is charging. No overloading of the service transformers is recorded for either case. Similar to the case with residential circuit, the charging station connected to the secondary load in the mixed circuit is also assumed to be charging multiple EVs sequentially. This results in an increase in kW demand and hence a voltage drop in the circuit from 6 pm to 8 am.

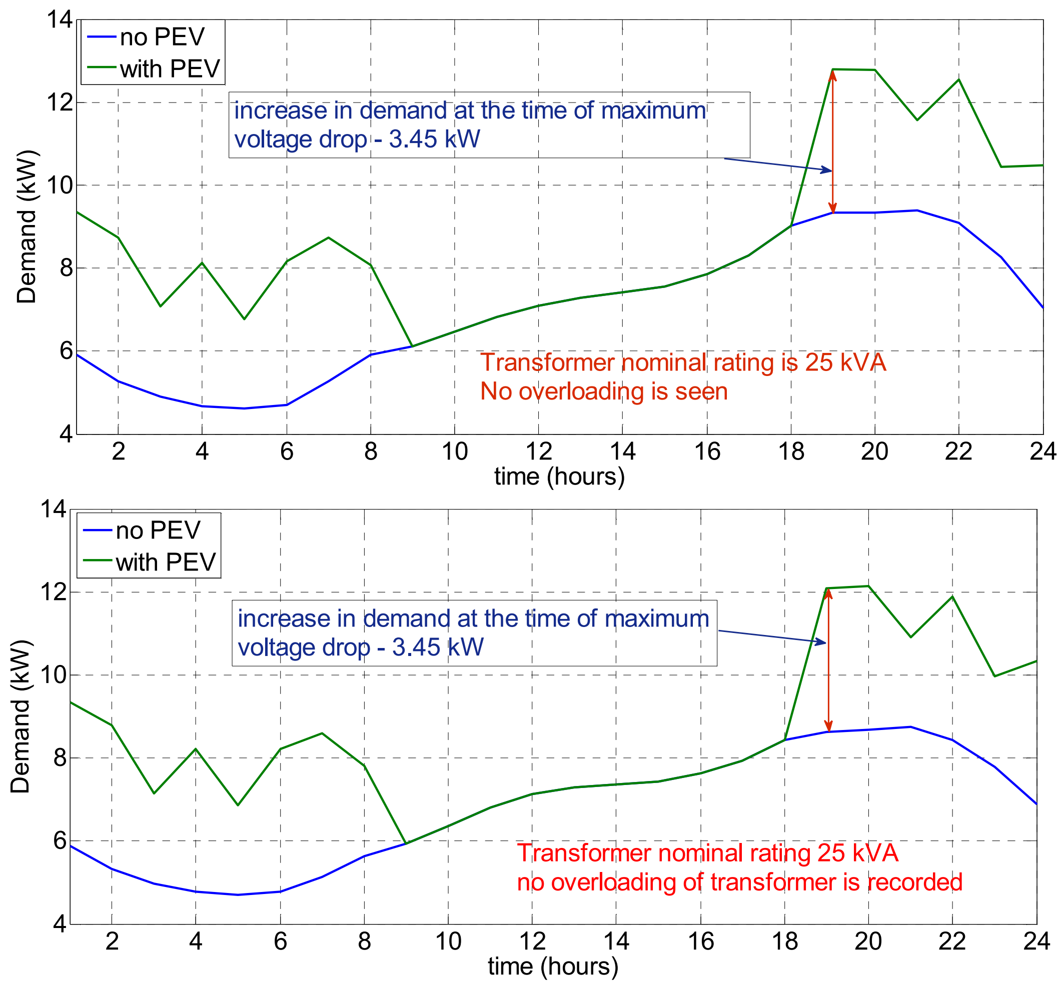


Fig. 5.2-4: Load shape profiles, with and without an EV load for the mixed distribution circuit. The service transformer is (a) distant from the substation and (b) nearby the substation

The largest voltage variations in the secondary network, due to EV charging are recorded and shown in Fig. 5.2-5. The largest voltage drops of about 1.5% and 0.9% are recorded for the remote and nearby service transformers, respectively. In either case, the largest voltage drop in the secondary is caused by the largest increase in kW demand (Fig. 5.2-4 and Fig. 5.2-5).

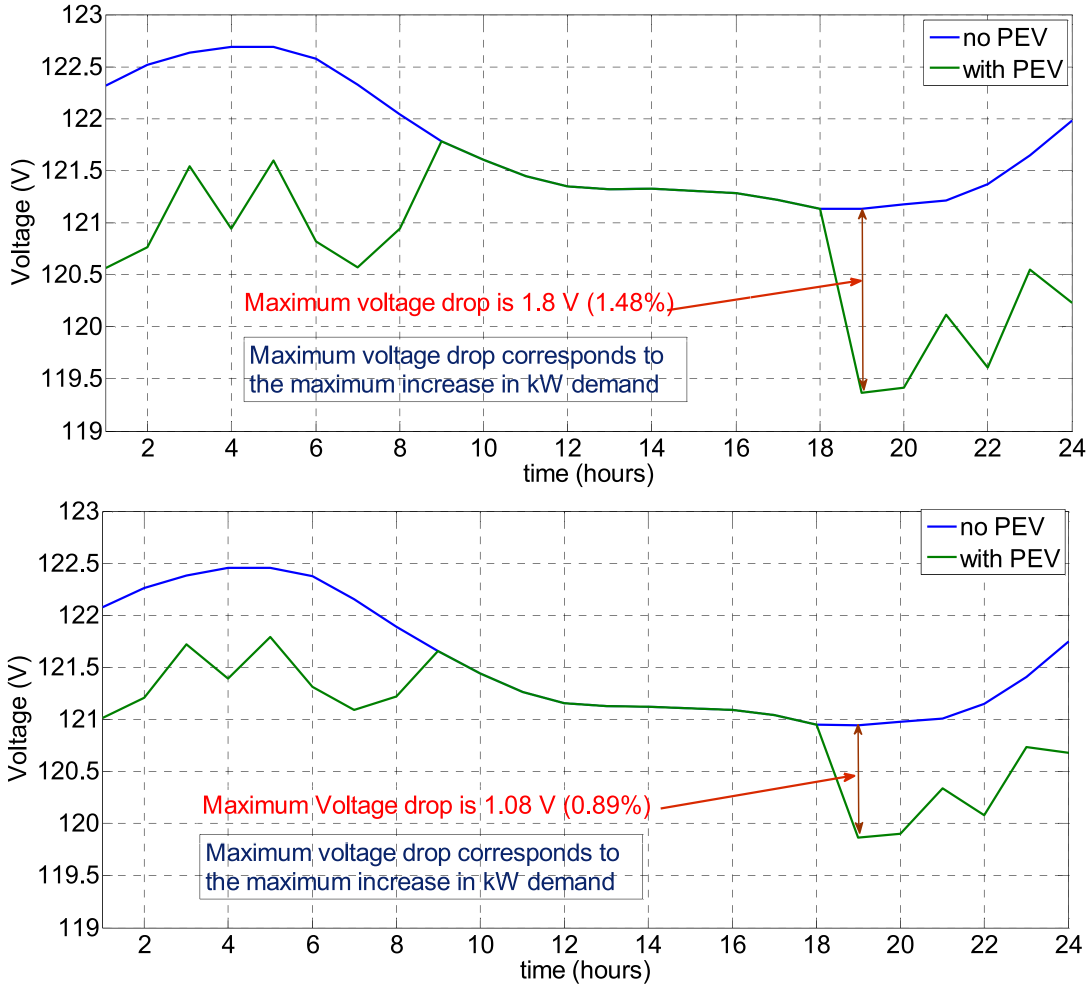


Fig. 5.2-5: Largest voltage drop recorded in the secondary network for the mixed distribution circuit. The service transformer is (a) remote from the substation and (b) nearby the substation

The largest voltage drop in each load node in the secondary networks under evaluation during the charging of an EV load is shown in Fig. 5.2-6. The location of the EV load is shown in a yellow-shaded rectangle.

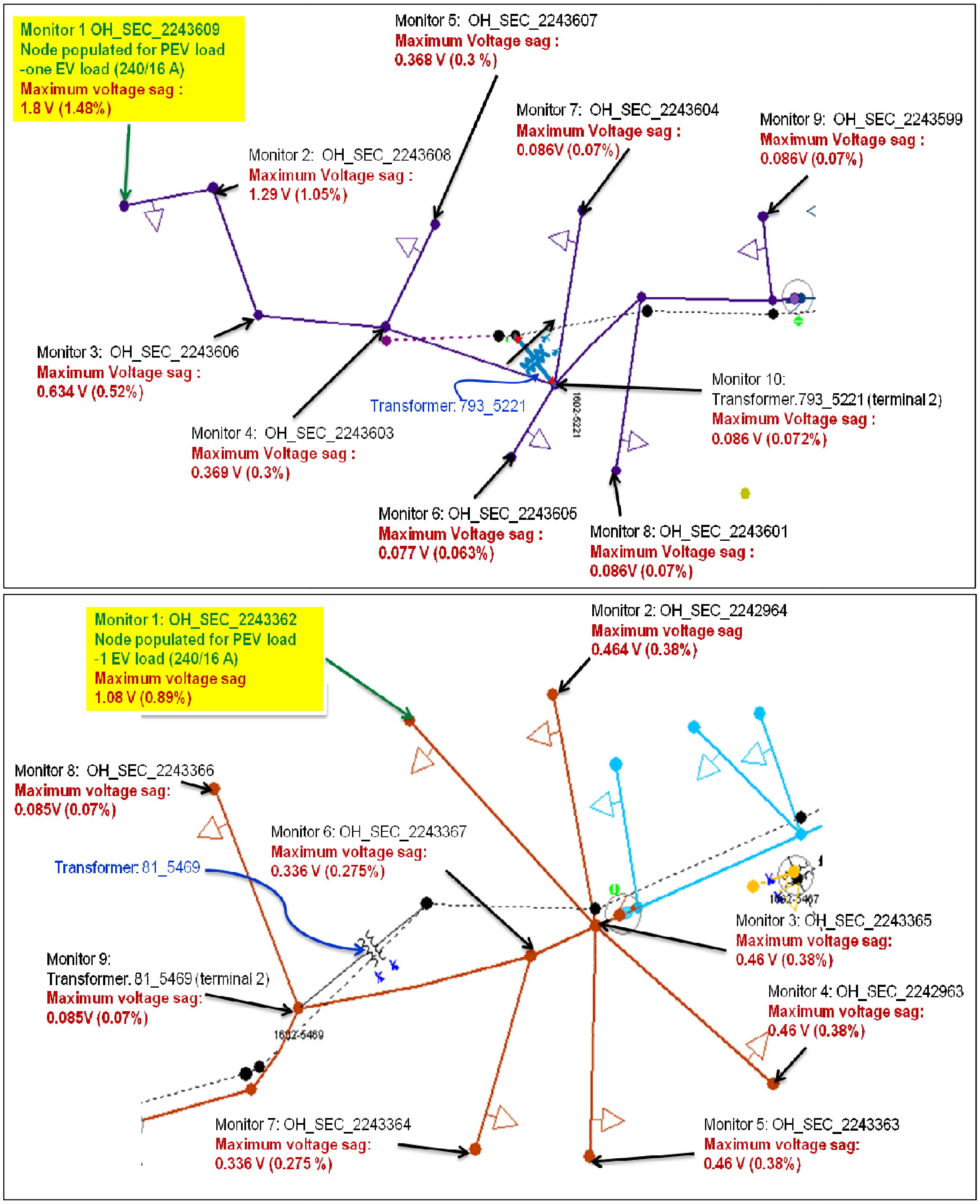


Fig. 5.2-6: Largest voltage drop in each load node during the EV load charging for the mixed distribution circuit. The service transformer is (a) remote from the substation and (b) nearby the substation

The following observations are made from a comparison of the voltage variation in both secondary networks during EV charging:

- Load nodes where the EV load is located or which lie in the charging current path of the EV load are affected most. However nodes off the charging path are less affected.
- Similar to the residential distribution feeder, the remote secondary network suffers larger voltage drop than the nearby secondary network. The magnitude of voltage drop in each network is compared in Table 5.2-5.

Load nodes in the secondary network	**Service transformer remote from the substation**	**Service transformer nearby the substation**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.48%)	1.08 V (0.89%)
Load nodes without EV, but in the EV charging current path	0.368 V (0.3 %)	0.46 V (0.38%)
Other non-EV load nodes	0.086 V (0.07%)	0.085 (0.07%)

Table 5.2-5: Effects of location of the service transformer with respect to the substation for a mixed (residential and commercial) circuit

5.2.3 Summary for the effects of location of the service transformer with respect to the substation

The analysis presented in Section 5.2.1 and 5.2.2 shows that a distant secondary network experiences a larger voltage drop during EV load charging. This conclusion is consistent for both types of distribution circuits, residential and mixed.

- The largest voltage drops in remote and nearby secondary networks during EV battery charging are approximately 1.5% and 1.0%, respectively.

- The largest voltage drop takes place at the load node where the EV load is located. Load nodes without EV load but in the EV charging current path also experience significant voltage drop. The remaining load nodes are least affected.

<table>
<tr><th>Observations drawn from the study</th><th colspan="2">Residential circuit</th><th colspan="2">Mix (residential and commercial) circuit</th></tr>
<tr><td rowspan="3">Largest voltage drop</td><td colspan="2">Service transformer is</td><td colspan="2">Service transformer is</td></tr>
<tr><td>Remote</td><td>Nearby</td><td>Remote</td><td>nearby</td></tr>
<tr><td>1.5%</td><td>1%</td><td>1.48%</td><td>0.9%</td></tr>
<tr><td>Location of service transformer for the largest voltage drop</td><td colspan="2">Remote from the substation</td><td colspan="2">Remote from the substation</td></tr>
<tr><td>Node affected most by EV charging</td><td colspan="2">Node where EV load is located</td><td colspan="2">Node where EV load is located</td></tr>
</table>

Table 5.2-6: Summary for the effects of location of the service transformer with respect to the substation

5.3 EFFECTS OF LOCATION OF THE EV LOADS WITH RESPECT TO THE SERVICE TRANSFORMER: NEARBY VS. REMOTE

The objective of this section is to evaluate effects of location of the EV loads with respect to the service transformer on voltage variation of the secondary network.

As discussed in Section 5.2 the secondary network distant from the substation is affected most by EV charging. Therefore to simulate worst case scenario a service transformer remote from the substation is chosen. Evaluation is done for both residential and mixed (commercial and residential) distribution circuits. Table 5.3-1 summarizes the evaluation conditions.

Evaluation parameters				
Location of EV loads w.r.t the service transformer	*Circuit type*	*Charging Station*	*Location of service transformer w.r.t the substation*	*Number of EVs in the secondary circuit*
Nearby vs. Remote	Residential	240 V/16A	Remote	One
Nearby vs. Remote	Mix	240 V/16A	Remote	One

Table 5.3-1: Parameters to evaluate effects of the location of the EV loads

The secondary network served by the chosen transformer is loaded with one 240V/16A EV charging station. Location of the EV charging station is varied to get two different evaluation cases, one with an EV load remote from the service transformer and the other with an EV load nearby the service transformer. Based on the analysis, the following observations are made:

- EV charging station located farther out from the service transformer tends to cause more voltage drop in the secondary network than those nearby the service transformer. This phenomenon is true for both residential and mixed distribution circuits.
- For both types of circuits, the largest voltage drop occurs when the EV charging station is remote from the service transformer and it is approximately 1.5%.

Details of the analysis for residential and mixed (residential and commercial) distribution circuit are presented in Section 5.3.1 and 5.3.2 respectively.

5.3.1 Effects of location of the EV load with respect to the service transformer for a residential circuit

This section evaluates effects of location of the EV load with respect to the service transformer on daily voltage profile of the secondary network. For this reason, a transformer remote from the substation is considered. Location of the EV load with respect to the service transformer is varied (remote/nearby) to obtain two charging scenarios. Characteristics of the secondary network served by the service transformer for the two charging scenarios are summarized in Table 5.3-2.

Location of EV w.r.t to the service transformer	Number of EV	Service transformer location	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)
Remote	One	Remote	37 kVA	8	36.6 kW	40.1 kW (overloading)
Nearby	One	Remote	37 kVA	8	36.6 kW	40.1 kW (overloading)

Table 5.3-2: Characteristics of the secondary networks under evaluation

Fig. 5.3-1 shows hourly load demand for the chosen service transformer with and without the EV load. Since one EV load is added in both charging scenarios (remote/nearby) the hourly load shape obtained is identical for either case. Also the time of operation of the EV charging station is chosen from 6 pm to 8 am; hence an increase in demand is recorded for that time period only. The service transformer is overloaded during peak demand hours.

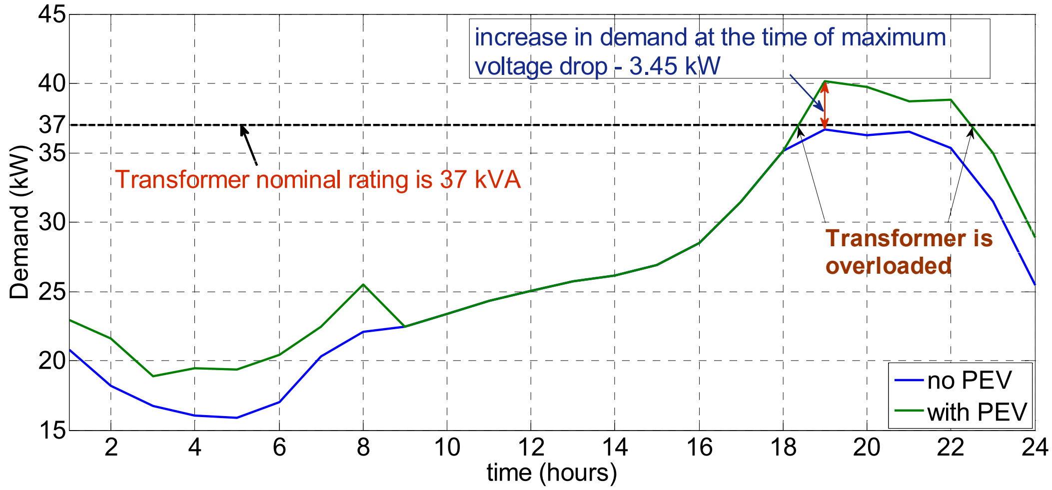


Fig. 5.3-1: Load shape profile, with and without an EV load (remote/nearby with respect to service transformer) for the residential circuit

Fig. 5.3-2 shows a comparison for the largest voltage variation recorded for the two cases (EV load - remote/nearby). The largest voltage drop recorded for remote and nearby EV loads are about 1.5% and 0.74%, respectively. Also for either case, the largest voltage drop in the secondary network corresponds to the largest increase in kW demand.

Since the EV charging station is assumed to be charging multiple EVs sequentially, an increased the kW demand and a voltage drop in the distribution network is recorded from 6 pm to 8 am. Because of the sequential charging of EV loads the largest increase in kW demand is 3.5 kW, which corresponds to the kW demand of one EV. Hence, the magnitude of the maximum voltage drop remains unaffected.

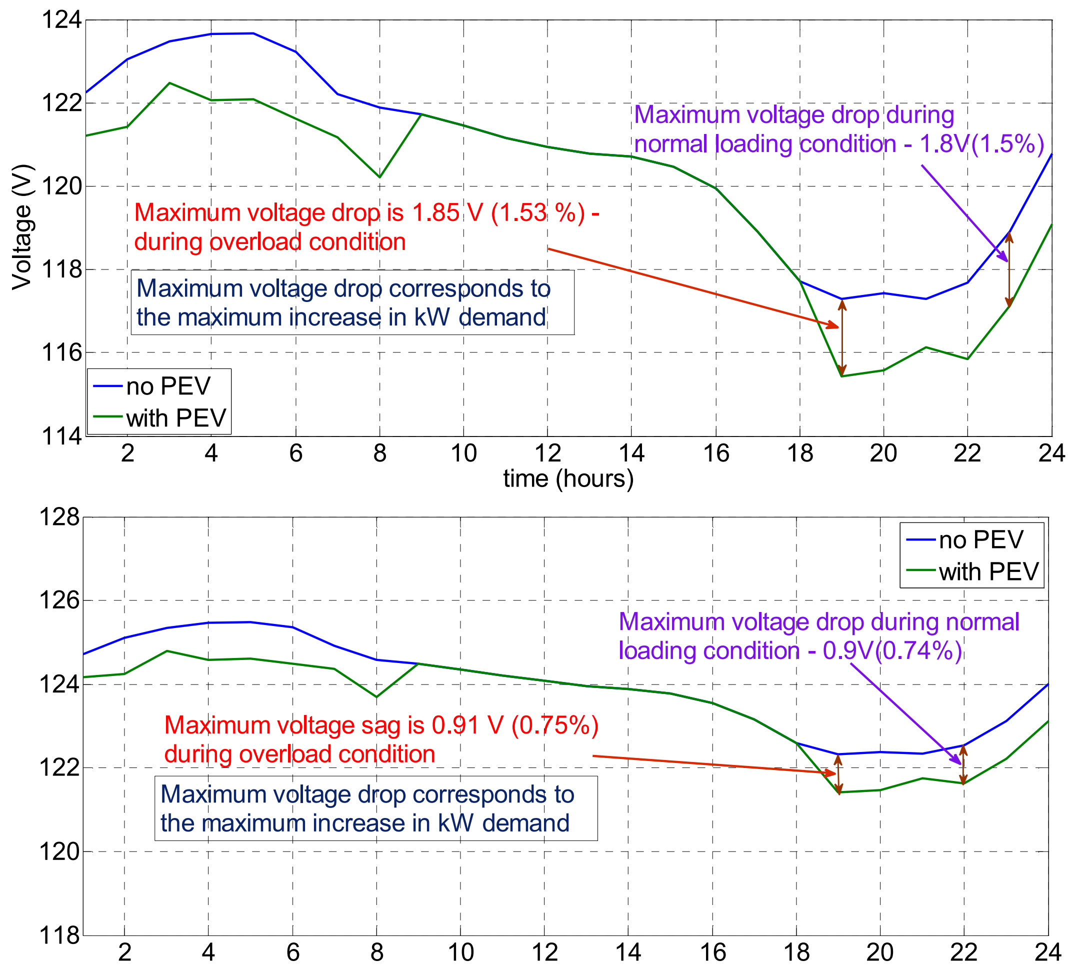
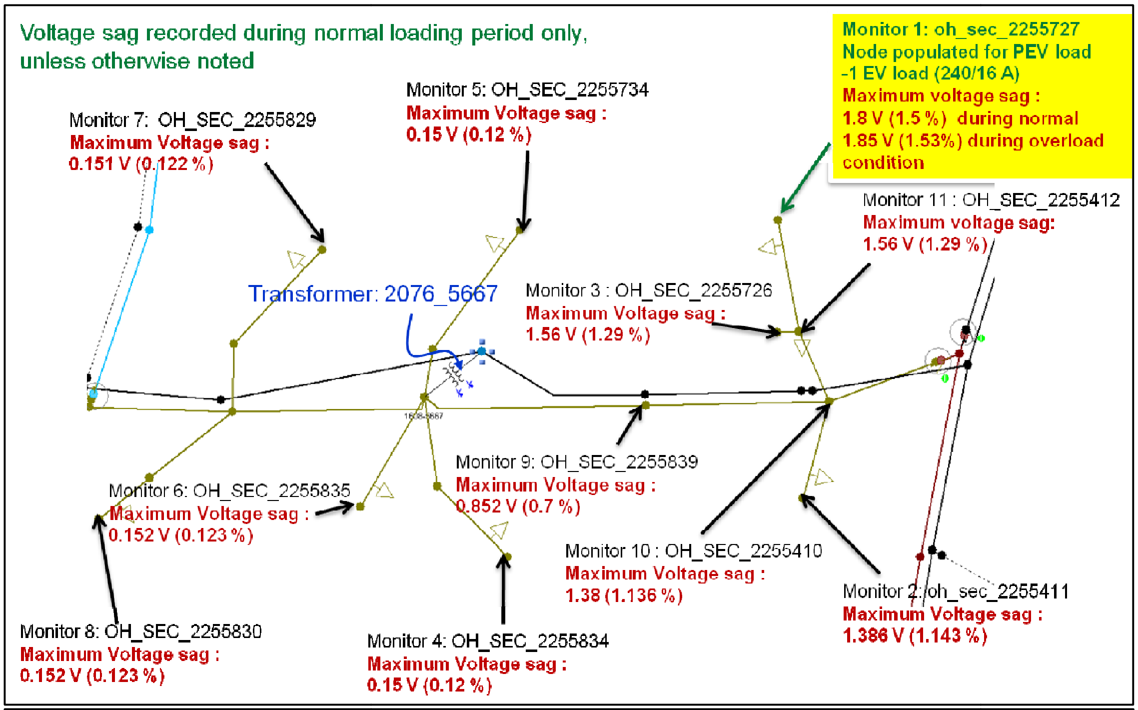


Fig. 5.3-2: Largest voltage drop recorded in the secondary networks for the residential circuit. The EV load is (a) distant from the service transformer and (b) nearby the service transformer

Fig. 5.3-3 shows the largest voltage drop at each load node in the secondary network under evaluation during the charging of an EV load. The location of the EV load is shown in a yellow-shaded rectangle.



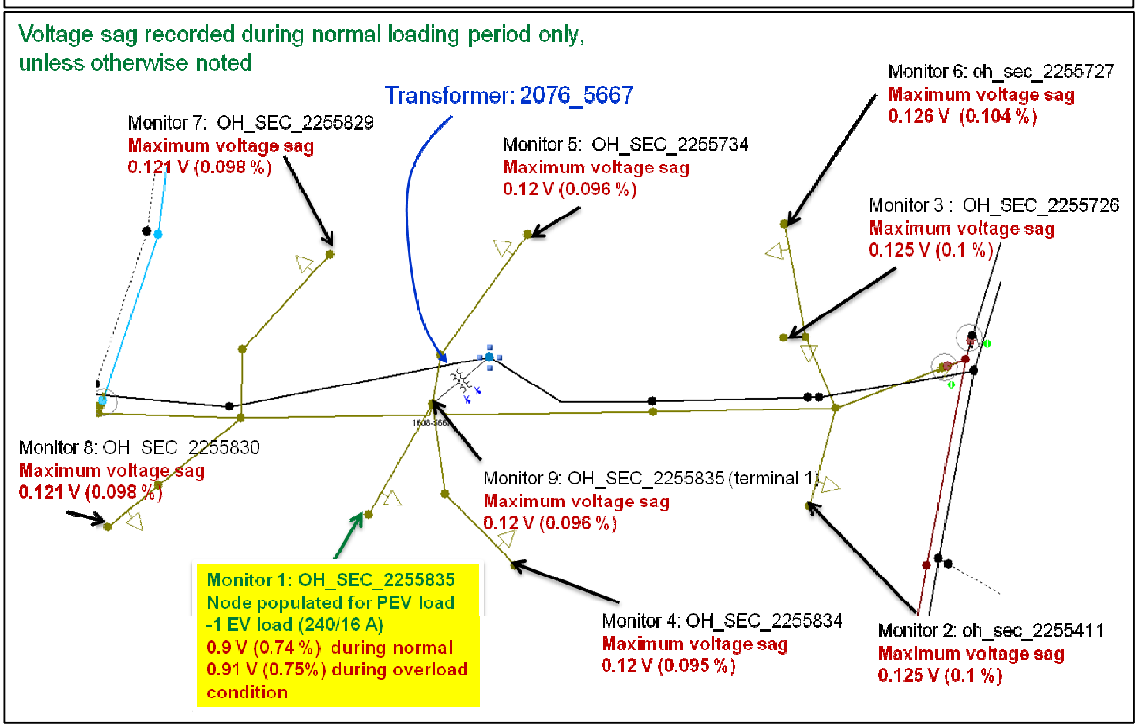


Fig. 5.3-3: Largest voltage drop in each load node during the EV load charging for the residential circuit. The EV load is (a) distant from the service transformer and (b) nearby the service transformer

By comparing voltage drops in the secondary network for both locations of the EV load (remote/nearby), the following observations are made:

- An EV load at the load node remote from the service transformer causes larger voltage drop in the secondary network. The amount of voltage drops for both locations of the EV load (remote/nearby) are compared in Table 5.3-3.
- The largest voltage drop takes place at the load node where the EV load is located while it is being charged. Load nodes in the EV charging current path also suffer comparable voltage drop. Load nodes off the charging path are much less impacted.

Load nodes in the secondary network	**EV load farthest from the transformer**	**EV load closest to the transformer**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.5%) During overload – 1.85 V (1.53%)	0.91 V (0.74%)
Load nodes without EV, but in the EV charging current path	1.56 V (1.3%)	0.126 V (0.1%)
Other non-EV load nodes	0.15 V (0.12%)	0.121 V (0.1%)

Table 5.3-3: Effects of location of the EV loads with respect to the service transformer for a residential circuit

5.3.2 Effects of location of the EV load with respect to the service transformer for a mixed residential and commercial circuit

A similar evaluation as in Section 5.3.1 is now performed for a mixed distribution circuit. A transformer remote from the substation is considered and location of the EV load with respect to the service transformer is varied (remote/nearby) to get two charging scenarios. Table 5.3-4 summarizes characteristics of the secondary network considered in this section.

Location of EV w.r.t to the service transformer	Number of EV	Service transformer location	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)
Remote	One	Remote	25 kVA	6	9.4 kW	12.8 kW
Nearby	One	Remote	25 kVA	6	9.4 kW	12.8 kW

Table 5.3-4: Characteristics of the secondary networks under evaluation

Hourly load demand as seen by the service transformer with and without an EV load for either case (EV load - remote/nearby) is shown in Fig. 5.3-4. The increase in kW demand is recorded when the EV load is charging.

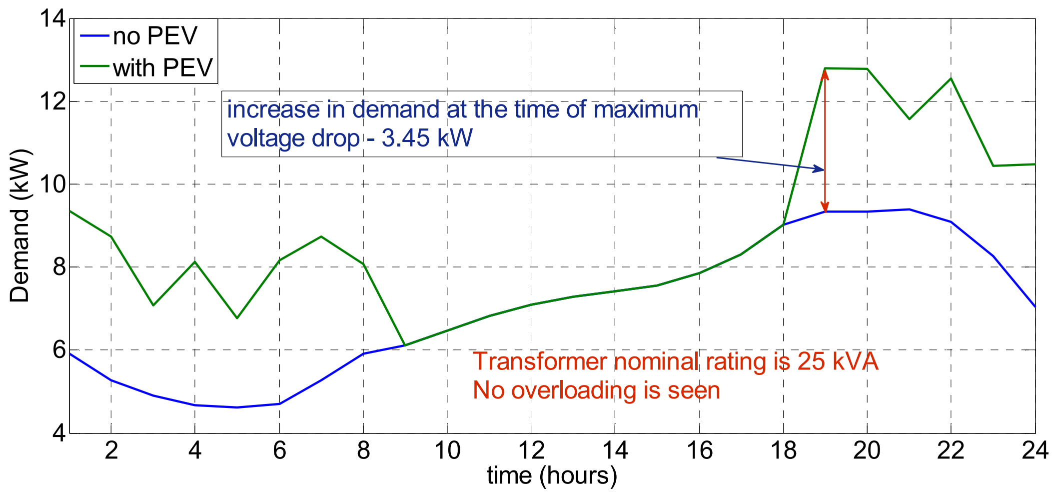


Fig. 5.3-4: Load shape profile, with and without an EV load (remote/nearby with respect to service transformer) for the mixed distribution circuit

A comparison for the largest voltage variation recorded for the two cases (EV load - remote/nearby) is drawn and shown in Fig 5.3-5. The largest voltage drops recorded for the remote and nearby EV load with respect to the service transformer are about 1.5% and 0.74%, respectively. Also for either case, the largest voltage drop recorded corresponds to the largest kW demand recorded in the secondary network. Since, the EV charging station is serving multiple EVs sequentially; hence, a voltage drop in the secondary network is recorded from 6pm to 8am.

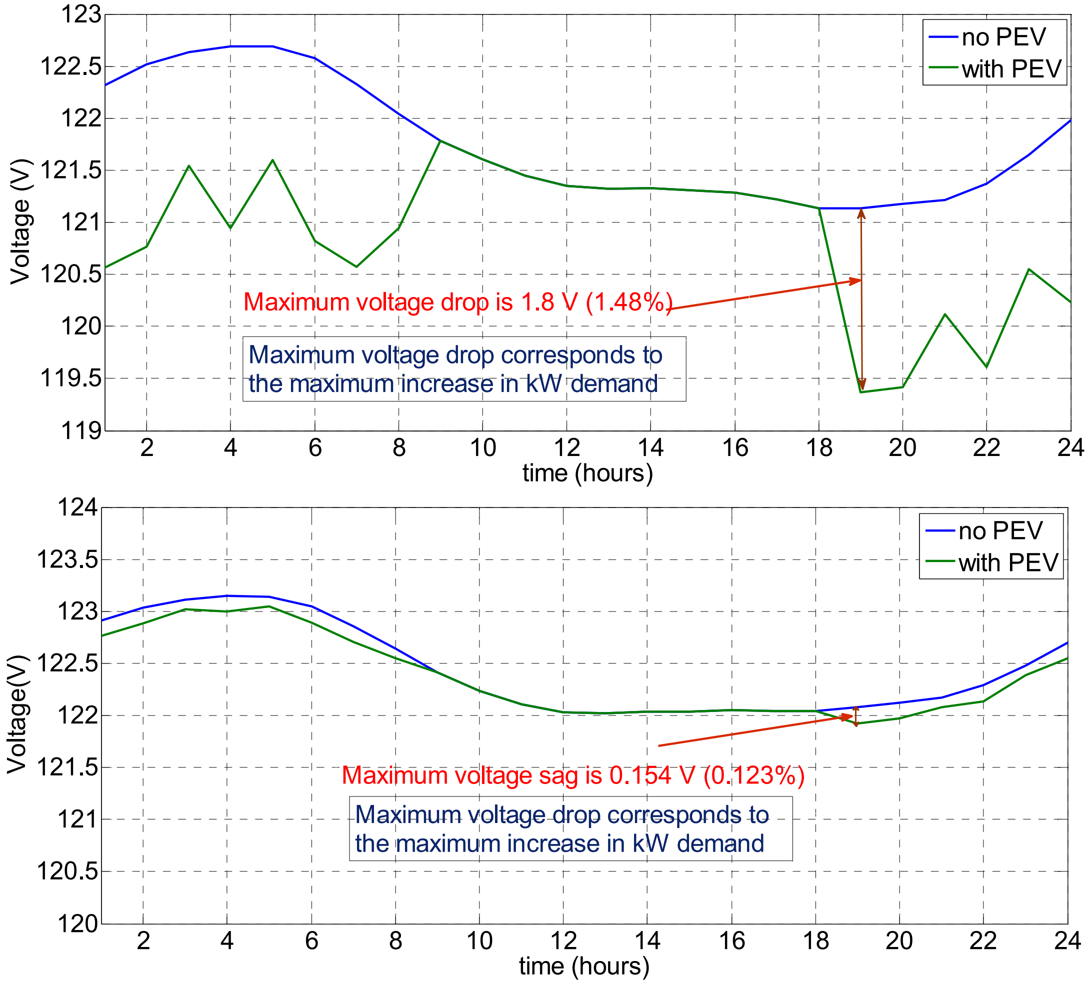


Fig.5.3-5: Largest voltage drop recorded in the secondary networks for the mixed circuit. The EV load is (a) distant from the service transformer and (b) nearby the service transformer

The largest voltage drop as seen by each load node in the secondary network is recorded and shown in Fig. 5.3-6. The location of the EV load is shown in a yellow-shaded rectangle.

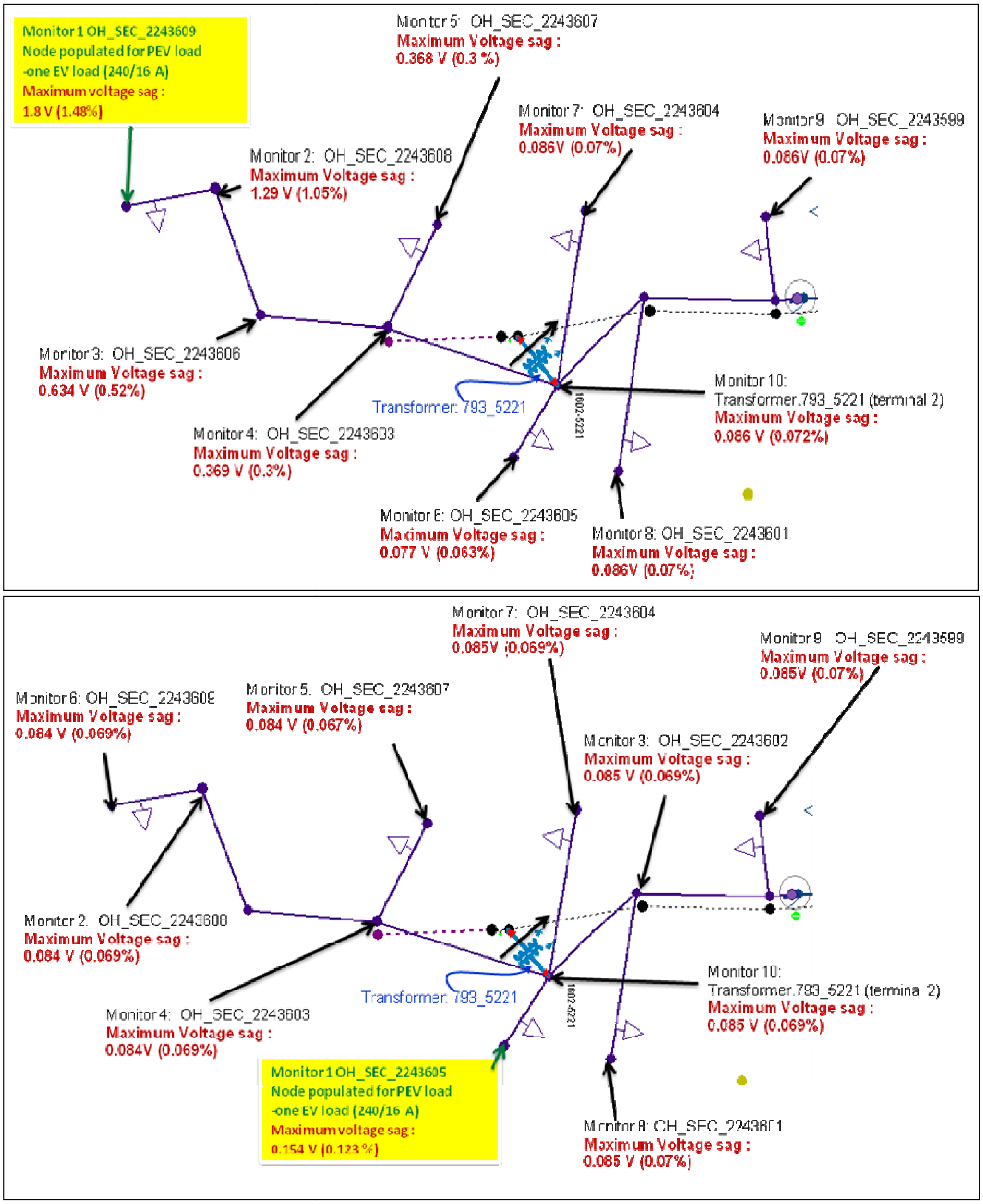


Fig. 5.3-6: Largest voltage drop in each load node during the EV load charging for the mixed distribution circuit. The EV load is (a) distant from the service transformer (b) nearby the service transformer

A comparison is drawn for both locations of the EV load with respect to the service transformer (remote/nearby). The following observations are made:

- Similar to the observations made for the residential circuits, an EV load located at the load node remote from the service transformer causes larger voltage drop in the secondary network. Detailed comparison is presented in Table 5.3-5.
- For the case when the EV load is located nearby the service transformer, the largest voltage drop for mixed circuit is 0.12%, which is much less than the voltage drop noted for the same case in the residential circuit (0.74%).
- Load nodes where the EV load is located or which lie in the charging current path of the EV load are affected the most.

Load nodes in the secondary network	**EV load farthest from the transformer**	**EV load closest to the transformer**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.48%)	0.154 V (0.12%)
Load nodes without EV, but in the EV charging current path	0.368 V (0.3 %)	0.085 V (0.07 %)
Other non-EV load nodes	0.086 V (0.07%)	0.085 V (0.07 %)

Table 5.3-5: Effects of location of the EV loads with respect to the service transformer for a mixed (residential and commercial) circuit

5.3.3 Summary for the effect of location of the EV load with respect to the service transformer

This study concludes that an EV load distant from the service transformer causes larger effect on the secondary network voltage profile. The phenomenon shows the same trend for both types of distribution circuits, residential and mixed. However, the magnitude of voltage drop is quite different for the two circuits because of difference in network topology. Based on the observations made in Section 5.3.1 and 5.3.2, following conclusions are drawn.

- For both the circuits the largest voltage drop is noted when the EV load is remote from the substation and is approximately 1.5%.
- For either circuit, the magnitude of the largest voltage drop decreases when the EV load is close to the service transformer.
- For the case when the EV load is nearby the service transformer, the largest voltage drop is different for the two circuits. The largest voltage drops for the residential circuit and the mixed circuit are 0.74% and 0.12 %, respectively. The reason could be attributed to the difference in topology of the two distribution feeders.
- The largest voltage drop takes place at the load node where the EV load is located, while it is being charged.

Observations drawn from the study	**Residential circuit**		**Mix (residential and commercial) circuit**	
Location of EV load for the largest voltage drop	Remote from the service transformer		Remote from the service transformer	
Node affected most by EV charging	Node where EV load is located		Node where EV load is located	
Largest voltage drop noted	EV load is		EV load is	
	Remote	Nearby	Remote	nearby
	1.5%	0.74%	1.48%	0.12%

Table 5.3-6: Summary for the effects of location of the EV load with respect to the substation

5.4 EFFECTS OF SIZE OF THE EV CHARGING STATION: 240V/16A VS. 240V/30A

The objective of this section is to evaluate the effect of size of the EV charging station on voltage variation of the secondary network. To simulate worst case scenario a service transformer remote from the substation is chosen for the study. The chosen secondary network is loaded with one EV charging station at the farthest load node from the service transformer. The evaluation is done for both residential and mixed distribution circuit. Table 5.4-1 summarizes the evaluation conditions.

Evaluation parameters				
Charging station size	*Circuit type*	*Location of service transformer from the substation*	*Location of EVs w.r.t the service transformer*	*Number of EVs in the secondary circuit*
240V/16 A vs. 240V/30 A	Residential	Remote	Remote	One
240V/16 A vs. 240V/30 A	Mix	Remote	Remote	One

Table 5.4-1: Parameters to evaluate effects of the EV charger size

The size of EV charging station is varied to get two different evaluation cases, one with a 240V/16A EV load and the other with a 240V/30A EV load. Based on the analysis, the following observations are made:

- A 240V/30A EV charging station causes more voltage drop in the secondary network as compared to a 240V/16A charging station. This phenomenon is true for both residential and mixed distribution circuits.
- For both types of circuit, the largest voltage drop occurs when the secondary network is loaded with a 240V/30A EV charging station. For residential and

mixed distribution circuits, the largest voltage drops are approximately 2.6% and 2.8%, respectively.

- For both the circuits, a 30-A EV load approximately doubles the largest voltage drop caused by a 16-A EV load.

Details of the analysis for residential and mixed circuits are presented in Section 5.4.1 and 5.4.2, respectively.

5.4.1 Effects of size of the EV charging station for a residential circuit

Effects of size of the EV charging station on voltage profile of the secondary network for a residential circuit are evaluated and compared in this section. The secondary network served by a service transformer remote from the substation is chosen for the study and is populated with an EV load at the farthest load node. Two charging scenarios are simulated for the comparison, one with a 16-A EV load and the other with a 30-A EV load. Characteristics of the secondary network served by the service transformer for the two cases are summarized in Table 5.4-2.

Size of the EV charging station	Number of EV	Service transformer location w.r.t. the substation	location of EV w.r.t to the service transformer	Rating of the transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)
240V/16A	One	Remote	Remote	37 kVA	8	36.6 kW	40.1 kW (overloading)
240V/30A	One	Remote	Remote	37 kVA	8	36.6 kW	43.1 kW (overloading)

Table 5.4-2: Characteristics of the secondary networks under evaluation

Fig. 5.4-1 shows hourly load demand for the service transformer for both types of the EV load (16A/30A). An increase in kW demand is noted when the EV load is charging (i.e. 6 pm to 8 am). As expected the maximum increase in kW demand for a 30-A EV load is almost twice than for a 16-A EV load. The service transformer is overloaded during peak demand hours.

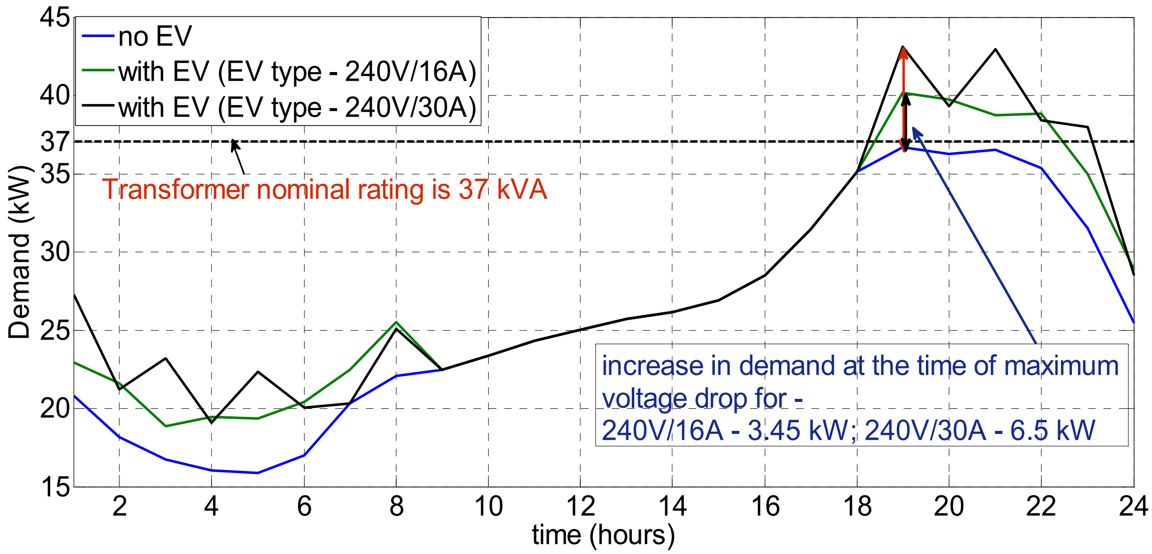


Fig. 5.4-1: Load shape profile, with and without an EV load for the residential circuit

Fig. 5.4-2 shows a comparison for the largest voltage variation recorded for the two types of EV charging station (16A/30A). During a normal loading condition, the largest voltage drop recorded for a 16A and a 30AEV load are about 1.5% and 2.6%, respectively. Also for either case, the largest voltage drop corresponds to the maximum kW demand for an EV load.

For both types of EV load, the largest voltage drop at each load node during the EV load charging is recorded and shown in Fig. 5.4-3. Since, EV charging stations are assumed to be charging multiple EVs sequentially, a voltage drop from 6 pm to 8 am is recorded in the secondary network. Because of the sequential charging of multiple EVs, the largest voltage drop recorded corresponds to the voltage drop due to the charging of one electric vehicle per charging station.

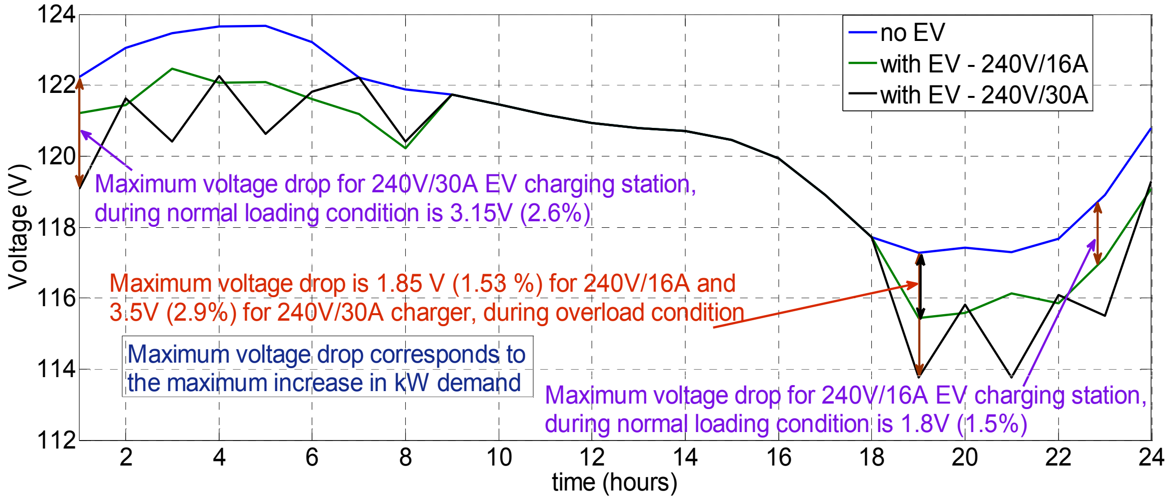


Fig. 5.4-2: Largest voltage drop recorded in the secondary network for EV loads type 240V/16A vs. 240V/30A.

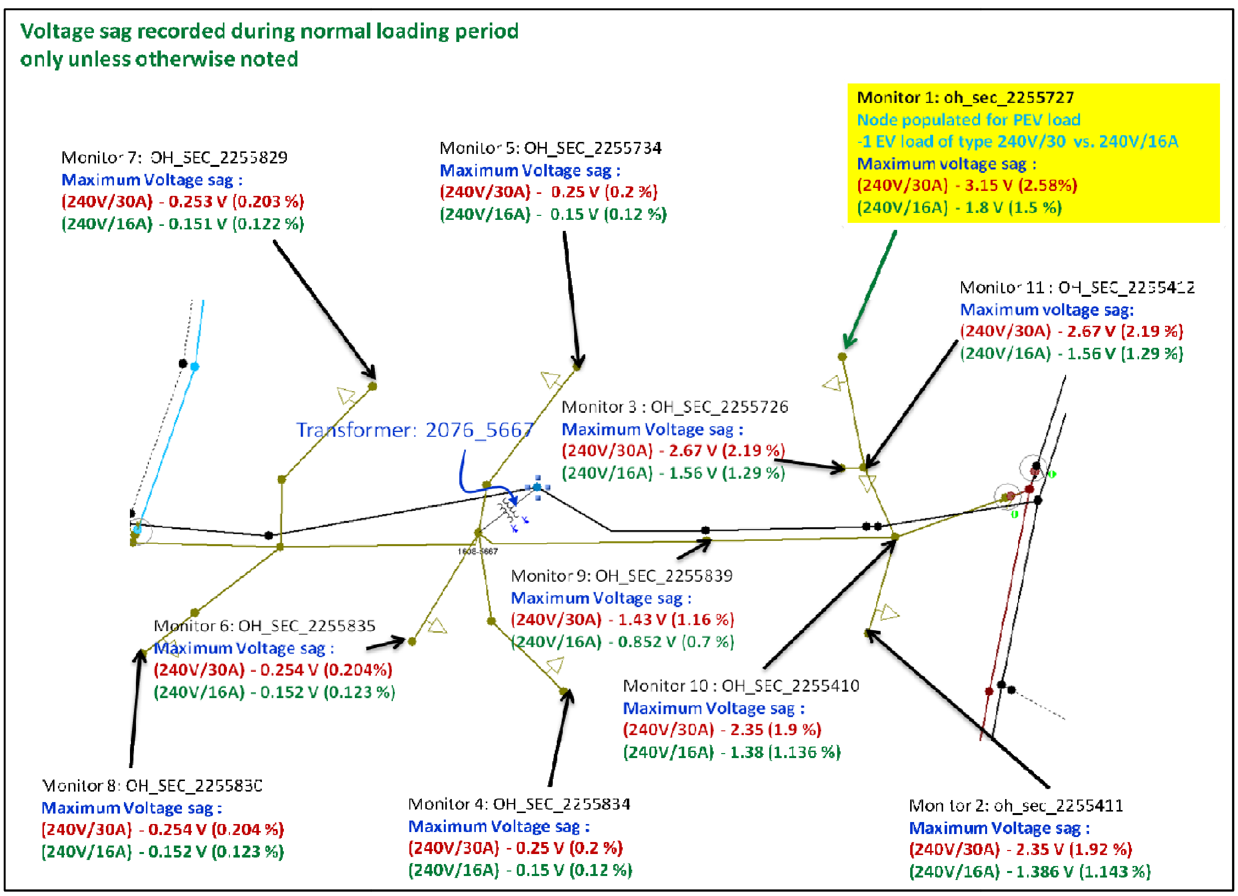


Fig. 5.4-3: Largest voltage drops in the secondary network for the residential circuit for both types of EV charging station (240V/16A vs. 240V/30A).

By comparing voltage drops in the secondary network for the two EV load size (16A/30A), the following observations are made:

- The largest voltage drop takes place at the load node where the EV load is located while it is being charged.
- A 30-A EV charging station causes more serious voltage drop in the secondary network than a 16-A EV charging station. A comparison for the magnitude of voltage drops for the two types of EV charging station are drawn in Table 5.4-3.

Load nodes in the secondary network	**EV charging station type 240V/16A**	**EV charging station type 240V/30A**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.5%) During overload - 1.85 V (1.53%)	3.15 V (2.58%) During overload – 3.52 V (2.9%)
Load nodes without EV, but in the EV charging current path	1.56 V (1.3%)	2.67 V (2.19%)
Other non-EV load nodes	0.15 V (0.12%)	0.25 V (0.2%)

Table 5.4-3: Effects of size of the EV charging station (16A/30A) for a residential circuit

5.4.2 Effects of size of the EV charging station for a mixed residential and commercial circuit

A similar evaluation as in Section 5.4.1 is now performed for a mixed distribution circuit. A secondary network remote from the substation is loaded with an EV load at the farthest load node. Two cases are simulated for each type of the EV load (16A/30A). Table 5.4-4 summarizes the characteristics of the secondary network considered for the study.

Size of the EV charging station	Number of EVs	Service transformer location	Location of EV w.r.t to the service transformer	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)
240V/16A	One	Remote	Remote	25 kVA	6	9.4 kW	12.8 kW
240V/30A	One	Remote	Remote	25 kVA	6	9.4 kW	15.9 kW

Table 5.4-4: Characteristics of the secondary networks under evaluation

Hourly load demand as seen by the service transformer for both types of EV load is shown in Fig. 5.4-4. An increase in kW demand is recorded when the EV load is charging.

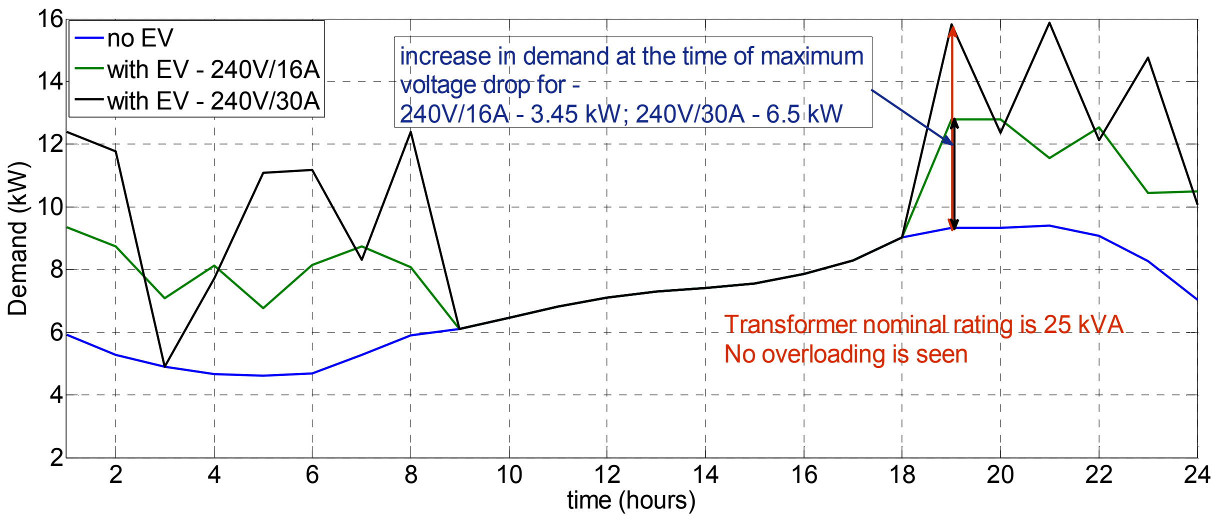


Fig. 5.4-4: Load shape profile, with and without an EV load for the mixed distribution circuit

The largest voltage drops recorded for a 16A and a 30AEV load are about 1.5% and 2.8%, respectively as shown in Fig. 5.4.5. Also for either case, the largest voltage drop recoded in the secondary network corresponds to the maximum increase in the kW demand.

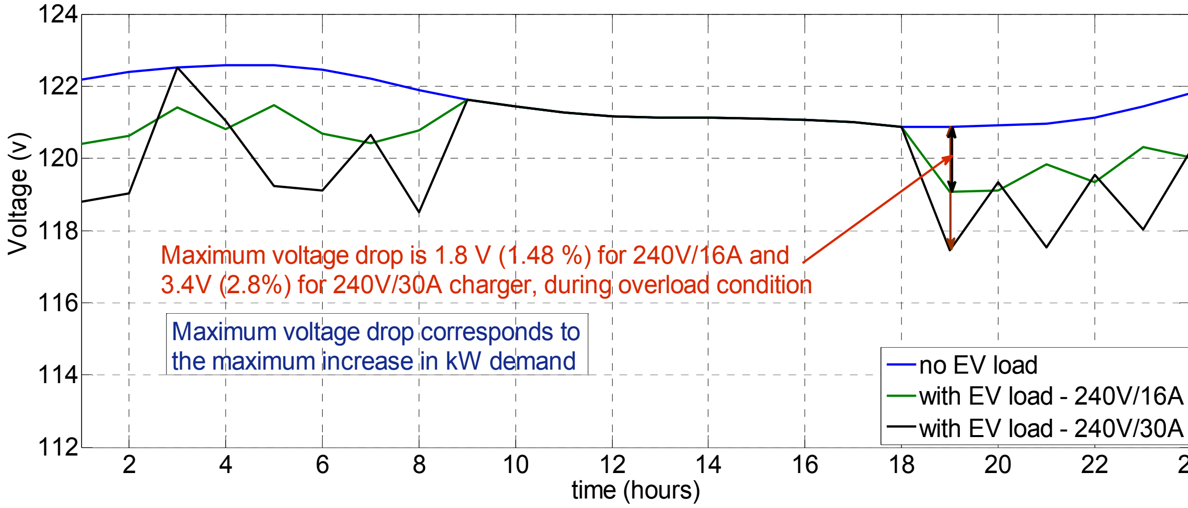


Fig. 5.4-5: Largest voltage drop recorded in the secondary network for EV loads type 240V/16A vs. 240V/30A

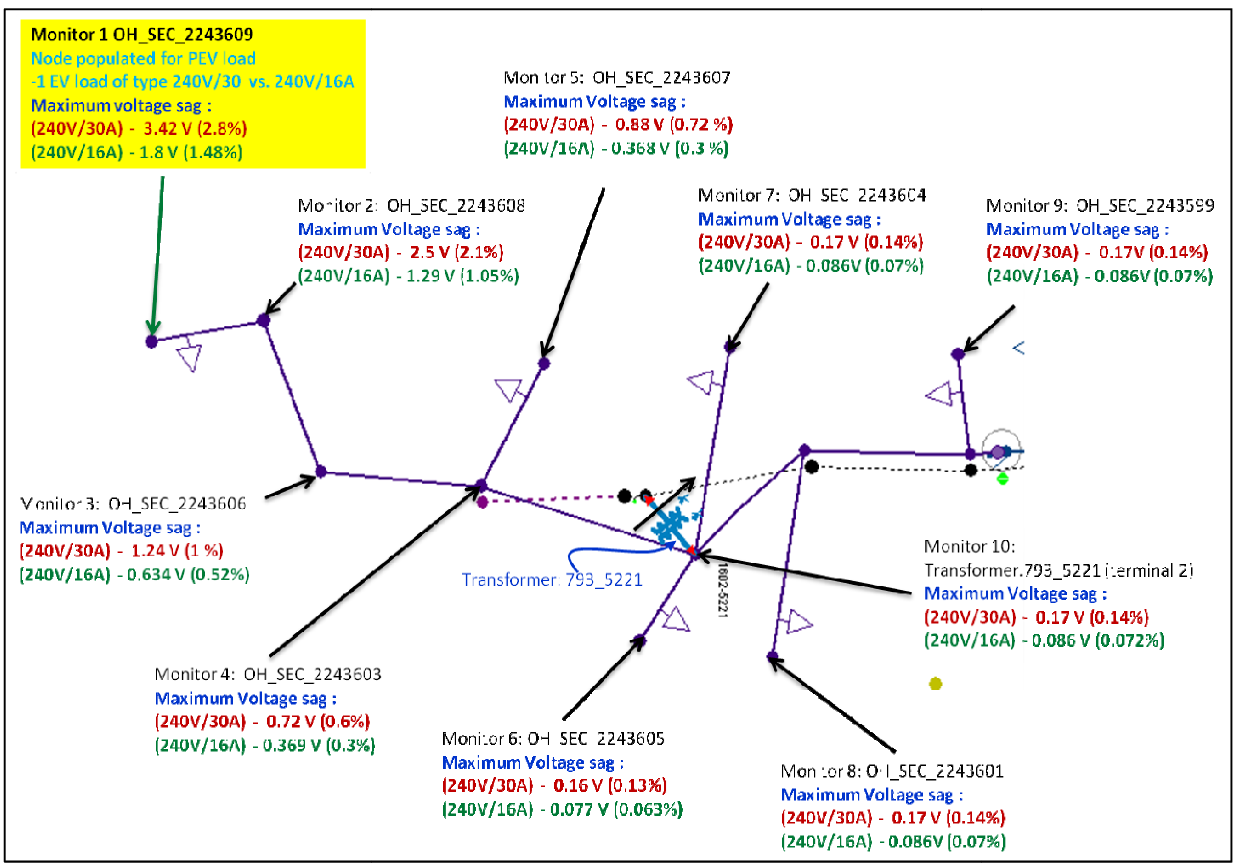


Fig. 5.4-6: Largest voltage drops in the secondary network for the mixed circuit for both types of EV charging station (240V/16A vs. 240V/30A)

The largest voltage drop as seen by each load node in the secondary network for both types of EV loads is recorded and is shown in Fig. 5.4-6. A comparison for the effects on the voltage quality of the secondary network is drawn for both types of EV load (16-A/30-A) and the following observations are made:

- Similar to the residential circuit, the largest voltage drop caused by a 240V/30A EV load is almost double of a 240V/16A EV load.
- Load nodes where the EV load is located or which lie in the charging current path of the EV load are affected most by EV charging.

Load nodes in the secondary network	**EV charging station type 240V/16A**	**EV charging station type 240V/30A**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.48%)	3.42 V (2.8%)
Load nodes without EV, but in the EV charging current path	0.368 V (0.3 %)	0.88 V (0.72%)
Other non-EV load nodes	0.086 V (0.07%)	0.17 V (0.14%)

Table 5.4-5: Effects of size of the EV charging station (16A/30A) for a mixed (residential and commercial) distribution circuit

5.4.3 Summary for the effect of size of the EV charging station

This study concludes that a 240V/30A EV charging station causes larger variations in the secondary network voltage profile. The phenomenon shows same trend for both types of distribution circuits, residential and mixed. Based on the observations made in section 5.4.1 and 5.4.2, the following conclusions are drawn.

- For both circuits the largest voltage drop gets almost double when the EV charging station is of size 240V/30A.
- The largest voltage drop takes place at the load node where the EV load is located while it is being charged.

Observations drawn from the study	**Residential circuit**		**Mix (residential and commercial) circuit**	
Size of EV load for largest voltage drop	240V/30A		240V/30A	
Node affected most by EV charging	Node where EV load is located		Node where EV load is located	
Largest voltage drop noted	EV charging station type		EV charging station is type	
	240V/16A	240V/30A	240V/16A	240V/30A
	1.5%	2.6%	1.48%	2.8%

Table 5.4-6: Summary for the effect of size of the EV charging station

5.5 Effect of Adding one Additional EV Load Adjacent to an Existing EV Load: One EV vs. One + One EV

This section evaluates the potential impact of adding an additional EV charging station on voltage profile of the secondary network. A secondary network distant from the substation is chosen. An EV charging station is added at the farthest load node from the service transformer. Now an additional EV charging station is added adjacent to the existing charging facility and the effects of additional EV load is evaluated. Evaluations are done for both residential and mixed distribution circuit. Table 5.5-1 summarizes the evaluation conditions

Evaluation parameters				
Number of EV charging station	*Circuit type*	*Location of service transformer from the substation*	*Location of EVs w.r.t the service transformer*	*Charging Station*
One vs. One + One	Residential	Remote	Remote	240V/16 A
One vs. One + One	Mix	Remote	Remote	240V/16 A

Table 5.5-1: Parameters to evaluate effects of adding one additional EV load adjacent to an existing EV load

Based on the analysis, the following observations are made:

- For both types of circuits, adding one additional EV load adjacent to an existing EV load causes higher voltage drop.
- The largest voltage drop for residential distribution circuit increases from 1.5% to 2.8% when an additional EV load is added.
- However an additional EV load on the mixed distribution circuit causes the largest voltage drop to increase to only 1.8% from 1.5%.

5.5.1 Effects of adding one additional EV load adjacent to an existing EV load for a residential circuit

Effects of an additional EV load added adjacent to an existing EV load for a residential circuit are evaluated in this section. The characteristics of the secondary network served by the transformer for the two charging scenarios are summarized in Table 5.5-2.

Number of EV	Service transformer location	location of EV w.r.t to the service transformer	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)
One	Remote	Remote	37 kVA	8	36.6 kW	40.1 kW (overloading)
One + One	Remote	Remote	37 kVA	8	36.6 kW	43.5 kW (overloading)

Table 5.5-2: Characteristics of the secondary networks under evaluation

Fig. 5.5-1 shows hourly load demand for the service transformer for the two cases (one EV and one + one EV). Clearly an additional EV increases the kW demand. For either case, the service transformer gets overloaded during the peak demand. The largest voltage drop corresponds to the maximum increase in kW demand.

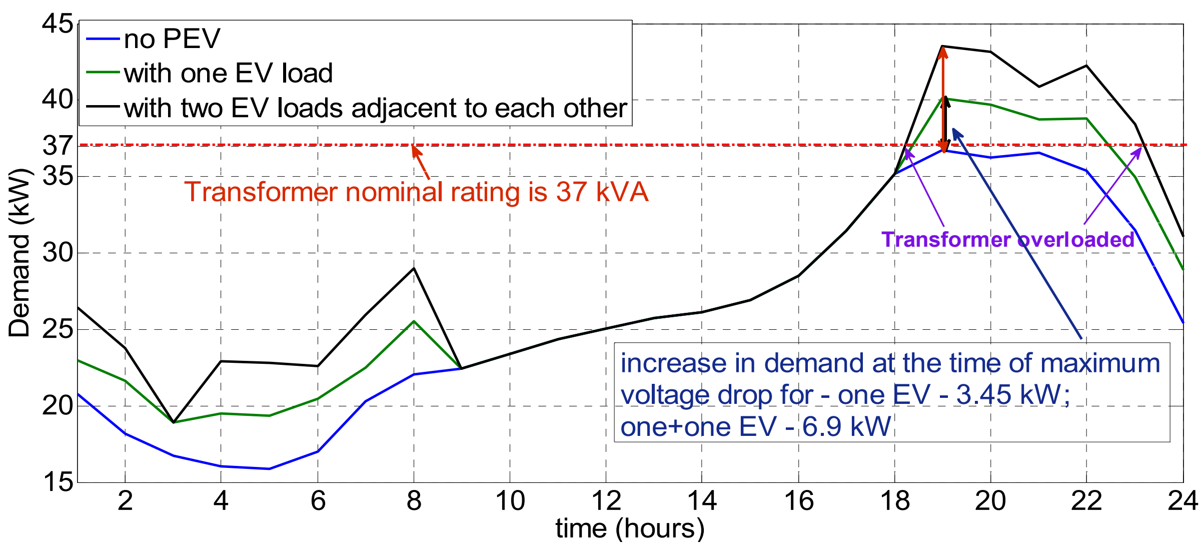


Fig. 5.5-1: Load shape profile, with and without an EV load (one EV vs. one+one EV) for the residential circuit

Fig. 5.5-2 shows the largest voltage variations recorded for the two cases. During normal loading conditions, adding an additional EV load increases the largest voltage drop in the secondary network from 1.5% to 2.8%.

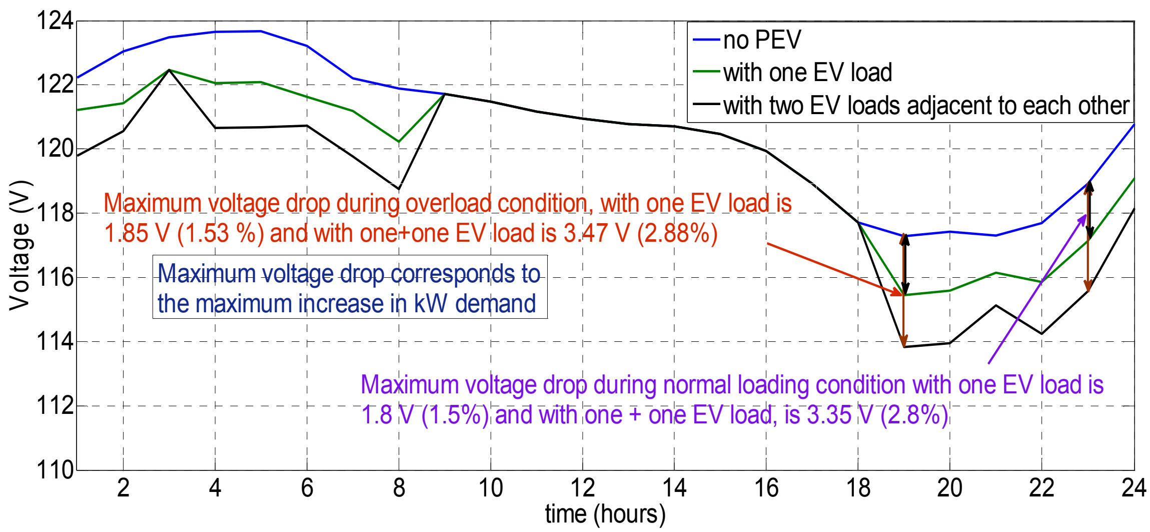


Fig. 5.5-2: Largest voltage drop (one EV vs. one+one EV) recorded in the secondary networks for the residential circuit.

Fig. 5.5-3 shows the largest voltage drop at each load node in the secondary network. Load nodes with EV loads are shown in a yellow-shaded rectangle. The voltage profile shown in Fig. 5.5-2, records a voltage drop from 6 pm to 8 am. This drop in voltage profile corresponds to the assumption that the EV charging station is serving multiple EV loads sequentially from 6 pm to 8 am.

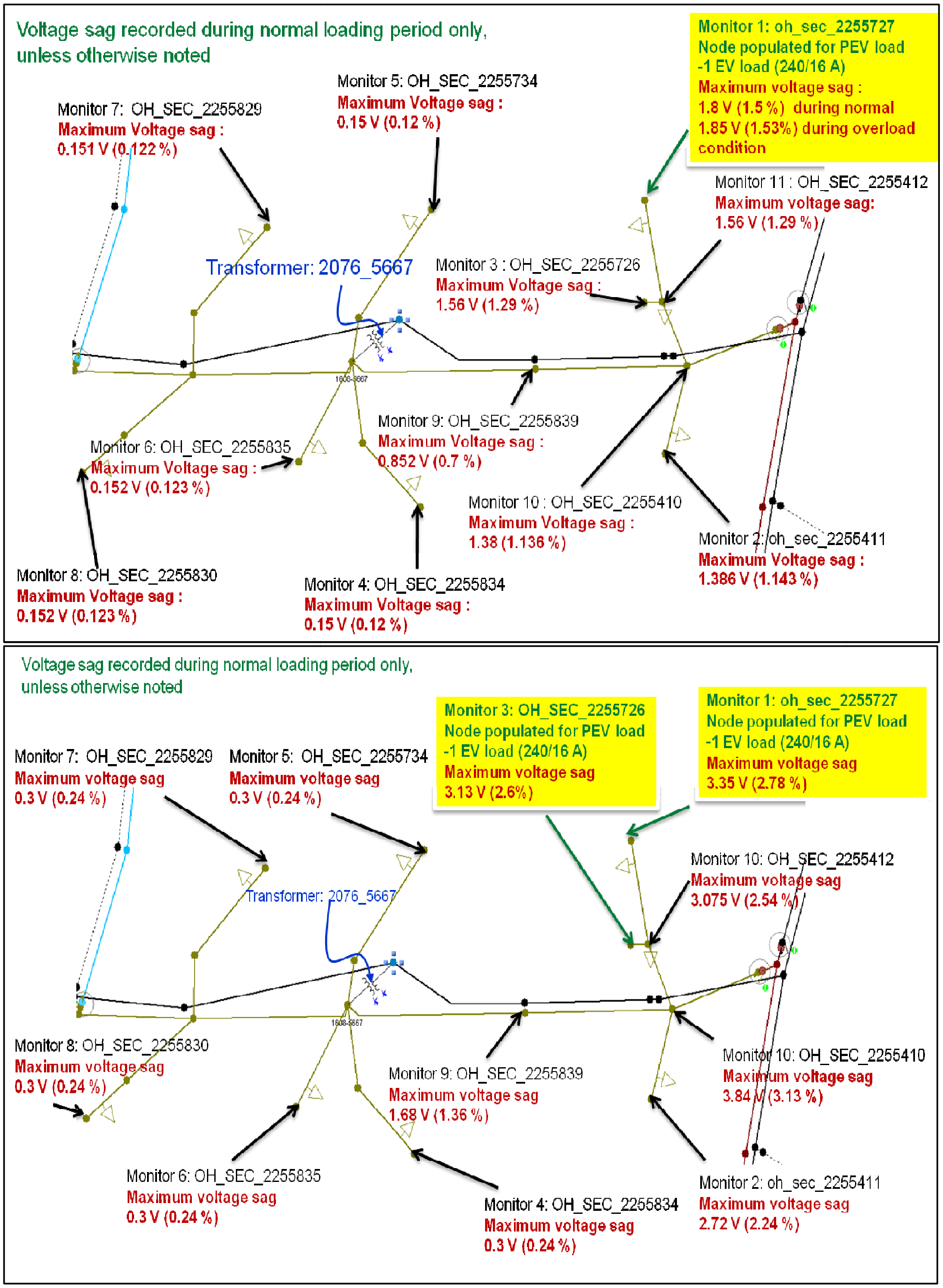


Fig. 5.5-3: Largest voltage drops in the secondary network for the residential circuit with (a) one EV load and (b) one + one EV load

Effects of adding an additional EV load adjacent to an existing EV load customer is evaluated and summarized as follows:

- The additional EV load increases the kW demand and the voltage drop in the secondary network.
- The largest voltage drop takes place at the load node where the EV load is located. During normal loading conditions, the largest voltage drop increases from 1.5% to 2.8% when an additional EV load is added.

Load nodes in the secondary network	**One EV load farthest from the transformer**	**One + One EV load farthest from the transformer**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.5%) During overload - 1.85 V (1.53%)	3.35 V (2.8%) During overload – 3.8 V (2.9%)
Load nodes without EV, but in the EV charging current path	1.56 V (1.3%)	3.13 V (2.6%)
Other non-EV load nodes	0.15 V (0.12%)	0.3 V (0.24 %)

Table 5.5-3: Effects of adding one additional EV load adjacent to an existing EV load for a residential circuit

5.5.2 Effects of adding one additional EV load adjacent to an existing EV load for a mixed residential and commercial circuit

A similar evaluation as in Section 5.5.1 is performed for a mixed distribution circuit. A service transformer remote from the substation is chosen and two cases, one with an EV load remote from the service transformer and the other with two EV loads adjacent to each other are simulated and compared. Table 5.5-4 summarizes characteristics of the secondary network.

Number of EV	Service transformer location	Location of EV w.r.t to the service transformer	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)
One	Remote	Remote	25 kVA	6	9.4 kW	12.8 kW
One + One	Remote	Remote	25 kVA	6	9.4 kW	16.3 kW

Table 5.5-4: Characteristics of the secondary networks under evaluation

Hourly load demands as seen by the service transformer with and without EV loads for either case are compared in Fig. 5.5-4.

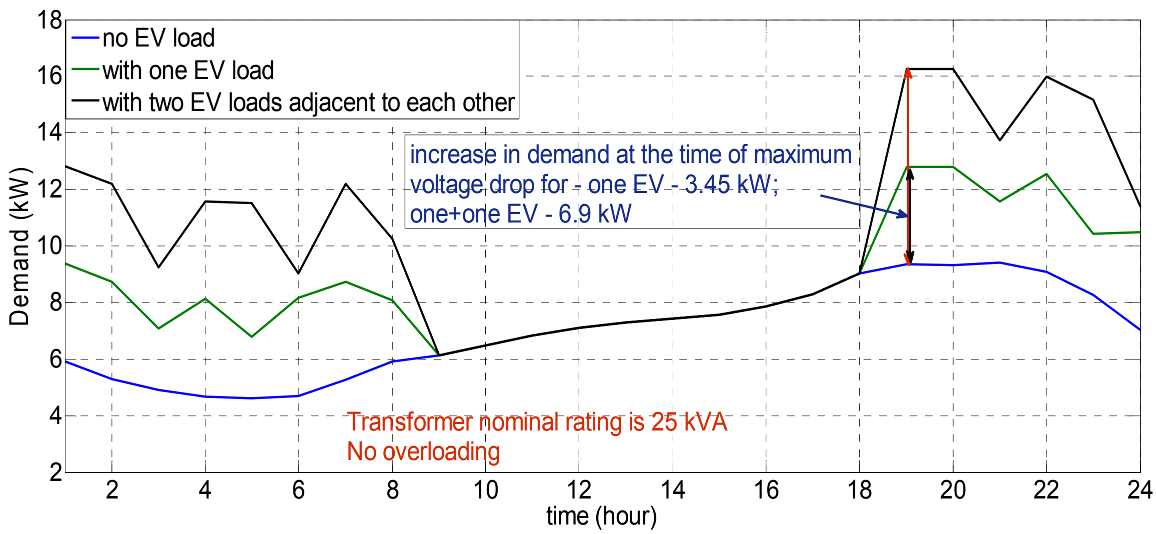


Fig. 5.5-4: Load shape profile, with and without an EV load (one EV vs. one+one EV) for the mixed distribution circuit

A comparison for the largest voltage variation recorded for the two cases, one with an EV and the other with two EVs adjacent to each other is shown in Fig 5.5-5. The largest voltage drop increases from 1.5% to 1.8% when an additional EV load is added.

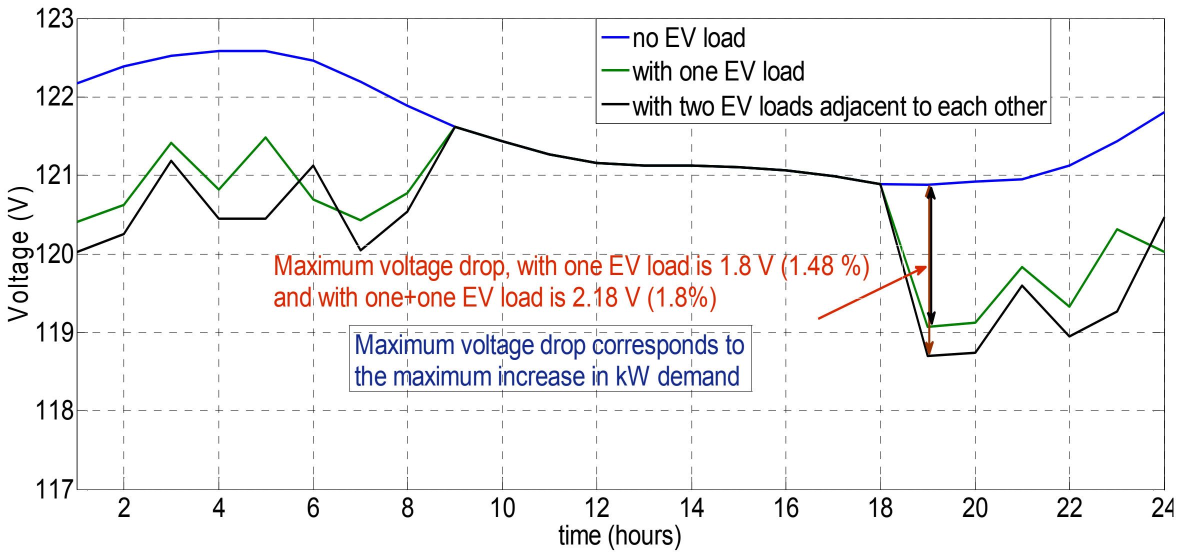


Fig. 5.5-5: Largest voltage drop (one EV vs. one+one EV) recorded in the secondary networks for the mixed distribution circuit.

The largest voltage drop as seen by each load node in the secondary network is recorded and shown in Fig. 5.5-6. Load nodes with the EV charging stations are shown in a yellow-shaded rectangle. Similar to the residential circuit, a voltage drop from 6 pm to 8 am is recorded in the secondary network. This voltage drop corresponds to an increase in kW demand corresponding to the multiple EVs getting charged sequentially by the EV charging station. Again the largest voltage drop still represents the voltage drop due to the charging of one electric vehicle per charging station.

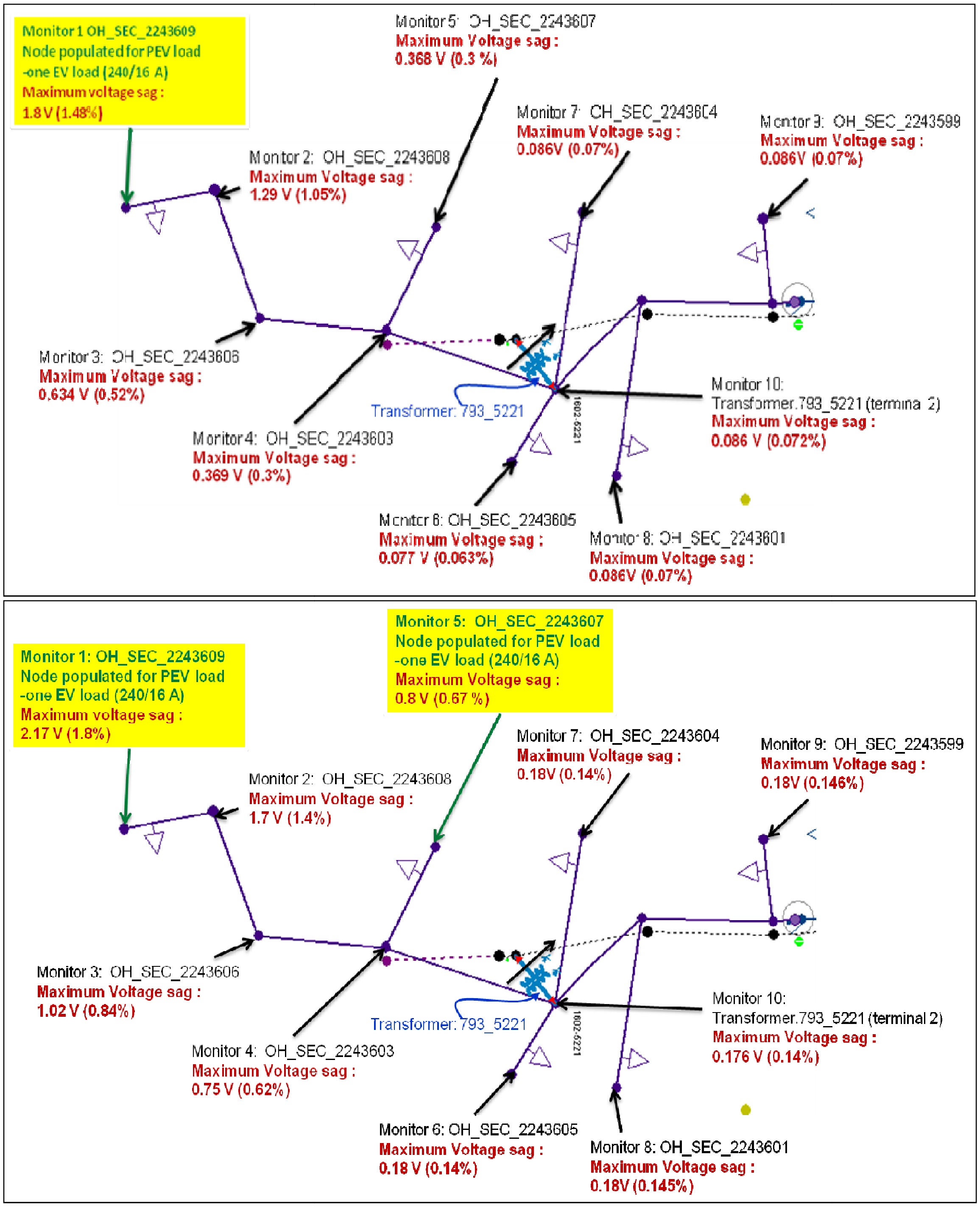


Fig. 5.5-6: Largest voltage drops in the secondary network for the mixed distribution circuit with; (a) one EV load and (b) one + one EV load

Evaluation for adding an additional EV load adjacent to an existing EV load is done and the following observations are made:

- Similar to the residential circuit, the additional EV load doubles the kW demand and increases the voltage drop in the secondary network.
- The largest voltage drop increases from 1.5% to 1.8% when an additional EV load is added.
- The largest voltage drop observed in the mixed distribution circuit when an additional EV load is added (1.8%) is less than the largest voltage drop recorded for an additional EV load in the residential circuit (2.8%).

Load nodes in the secondary network	**One EV load farthest from the transformer**	**One + One EV load farthest from the transformer**
	Largest voltage drop	Largest voltage drop
Load node with one EV	1.8 V (1.48%)	2.18 V (1.8%)
Load nodes without EV, but in the EV charging current path	0.368 V (0.3 %)	0.8 V (0.67%)
Other non-EV load nodes	0.086 V (0.07%)	0.18 V (0.14 %)

Table 5.5-5: Effects of adding one additional EV load adjacent to an existing EV load for a mixed distribution circuit

5.5.3 Summary for effects of adding one additional EV load adjacent to an existing EV load

This study concludes that adding an additional EV load adjacent to an existing EV load increases the voltage drop in the secondary network. The largest voltage drop also increases as the overall kW demand increases. Though both types of distribution circuits, residential and mixed, show a similar trend, the percentage increase in voltage drop is quite different for the two circuits. This difference could be attributed to the difference in the network topology. Based on the observations made in Section 5.5.1 and 5.5.2, the following conclusions are drawn.

- For either circuit, an additional EV load increases the voltage drop in the secondary network.
- The largest voltage drop takes place at the load node where the EV load is located while it is being charged.
- The magnitude of the voltage drop on adding an additional EV load is different for the two circuits. The largest voltage drops for the residential and the mixed distribution circuits are 2.8% and 1.8%, respectively.

<table>
<tr><th>Observations drawn from the study</th><th colspan="2">Residential circuit</th><th colspan="2">Mixed (residential and commercial) circuit</th></tr>
<tr><td>Increase in voltage drop on adding an additional EV load</td><td colspan="2">1.5% to 2.8%</td><td colspan="2">1.5% to 1.8%</td></tr>
<tr><td>Node affected most by EV charging</td><td colspan="2">Farthest load node where the EV load is located</td><td colspan="2">Farthest load node where the EV load is located</td></tr>
<tr><td rowspan="3">Largest voltage drop noted</td><td colspan="2">Number of EV load</td><td colspan="2">Number of EV load</td></tr>
<tr><td>One</td><td>One + One</td><td>One</td><td>One + One</td></tr>
<tr><td>1.5%</td><td>2.8%</td><td>1.48%</td><td>1.8%</td></tr>
</table>

Table 5.5-6: Summary for the effects of adding one additional EV load adjacent to an existing EV load

Chapter 6: Evaluation of voltage variations on the secondary networks supplied by a three phase service transformer

The objective of this Chapter is to evaluate effects of location of the service transformer with respect to the substation on voltage variation of the secondary network served by a three-phase service transformer. The charging scenarios simulated are summarized in Table 6-1.

Circuit parameters under evaluation	**Different conditions evaluated for**	**Condition for the largest voltage drop**
Location of the service transformer w.r.t the substation	Remote from the substation	Service transformer remote from the substation
	Nearby the substation	

Table 6-1: Factors evaluated for their impact on the secondary network served by a three-phase transformer

The evaluation procedure is similar to a single-phase secondary network. A three-phase distribution transformer with typical kVA rating from 50 kVA/phase to 100 kVA/phase serving a three-phase secondary network is selected. Three 208V/16A EV charging stations are populated in a balanced configuration at the distant load node. The distance of the secondary network is varied to get two different charging scenarios, one with the secondary network far from the substation and the other with the secondary network close to the substation.

Evaluation parameters				
Location of service transformer	*Circuit type*	*Charging Station*	*Location of EV w.r.t. the service transformer*	*Number of EVs in the secondary circuit*
Remote vs. Nearby	Mixed	208 V/16A	Remote	Three

Table 6-2: Parameters to evaluate effects of location of the service transformer

The analysis is done for the mixed commercial and residential distribution circuit. Table 6-2 summarizes the evaluation conditions. Based on the analysis, the following observations are made:

- The secondary networks farther out from the substation tend to have lower voltage magnitudes than those nearby the substation.
- The largest voltage drop occurs when the service transformer is remote from the substation and is approximately 0.54%.

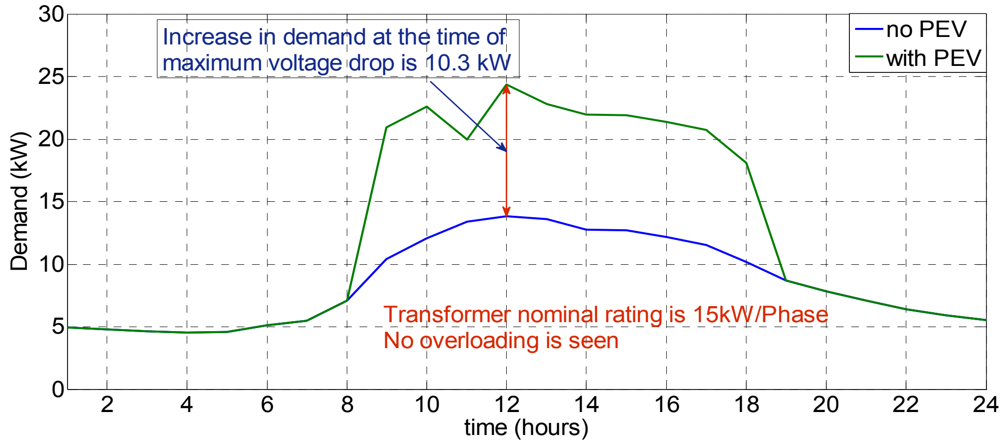
6.1 EFFECTS OF LOCATION OF THE THREE-PHASE SERVICE TRANSFORMER WITH RESPECT TO THE SUBSTATION

For the purpose of comparison, two three-phase transformers are chosen: one remote and one nearby the substation. It should be noted that both transformers chosen for the analysis are serving three-phase commercial loads. The characteristics of the secondary networks are summarized below.

Service transformer location	Rating of transformer per phase	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)	Number and location of EV w.r.t to the service transformer
Remote	15 kVA	6	14 kW	24 kW	Three and remote
Nearby	100 kVA	6	27 kW	37 kW	Three and remote

Table 6.1-1: Characteristics of the secondary networks under evaluation

Fig. 6.1-1 shows hourly load demand for the two locations of the service transformers (remote/nearby). An increase in the kW demand is recorded when the EV load is charging. It should be noted that the charging time for the EV loads is 8 am to 6 pm, which is different from the charging time chosen for the EVs connected to a single-phase distribution circuit in Chapter 4 (6 pm to 8 am). Since in this case the charging station is at a commercial facility, hence a charging duration from 8 am to 6 pm provides a more accurate representation. No overloading of the service transformers is recorded for either case.



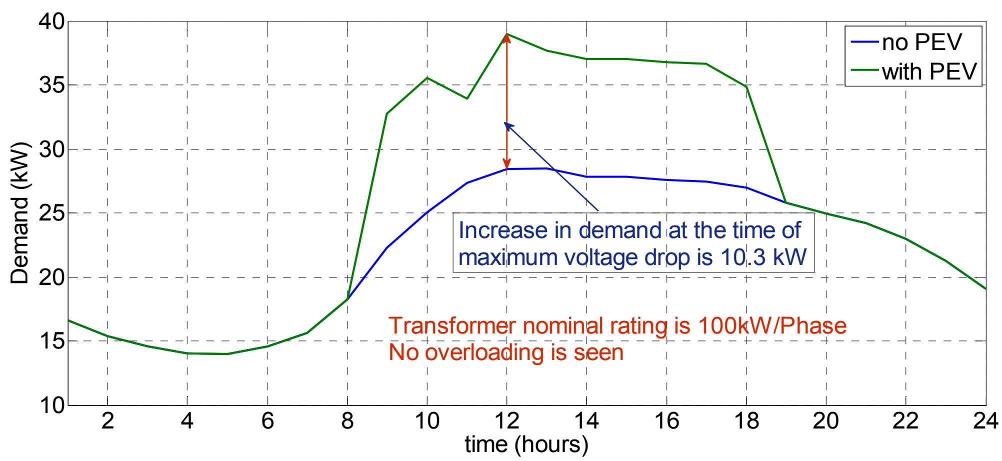


Fig. 6.1-1: Load shape profiles, with and without EV loads for the mixed distribution circuit. The service transformer is (a) distant from the substation and (b) nearby the substation

The largest voltage variations in the secondary network, due to EV charging are recorded and shown in Fig. 6.1-2. The largest voltage drop of about 0.54% and 0.123% are recorded for the remote and nearby service transformers, respectively. For either case, the largest voltage drop corresponds to the maximum increase in the kW demand.

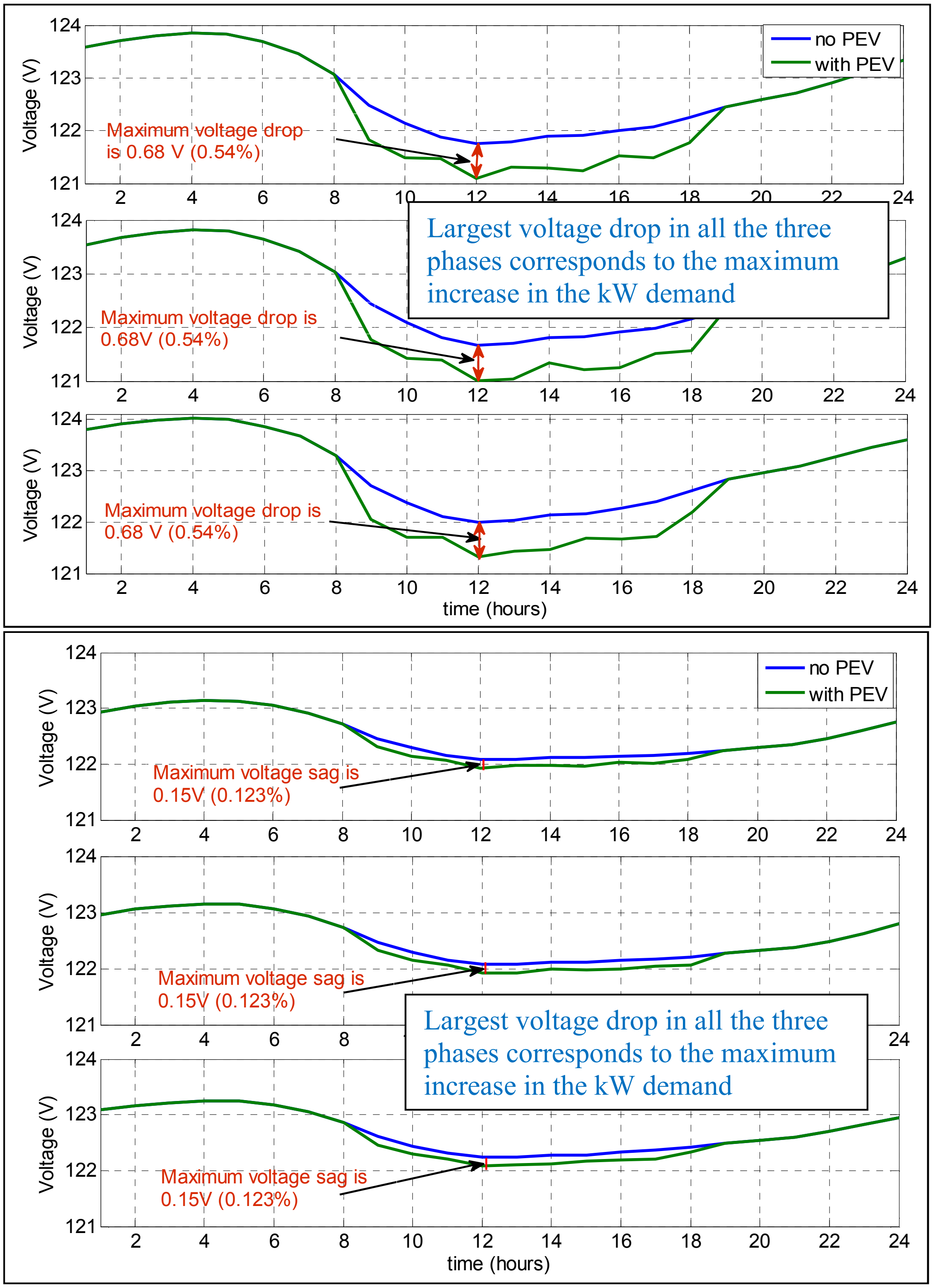


Fig.6.1-2: Largest voltage drop recorded in the secondary network for the mixed distribution circuit. The service transformer is (a) remote from the substation and (b) nearby the substation

Fig. 6.1-3 shows the largest voltage drop at each load node in the secondary network. The load node where the EV loads are located is shown in a yellow-shaded rectangle.

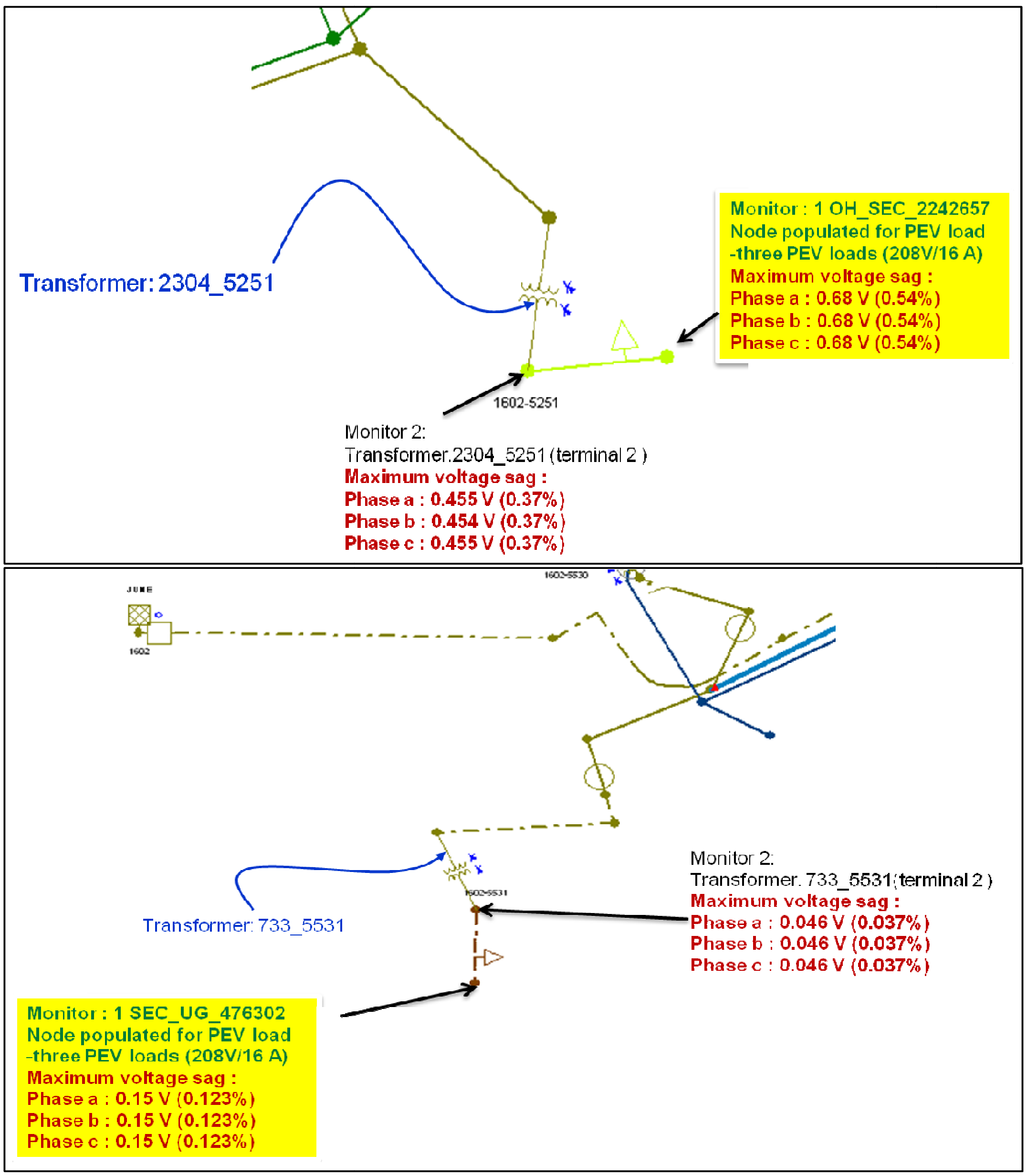


Fig. 6.1-3: Largest voltage drop in each load node during the EV load charging. The service transformer is (a) remote from the substation and (b) nearby the substation

A comparison for the voltage variations for both locations of the secondary networks due to EV charging is drawn and the following observations are made:

- Load nodes where the EV load is located are affected most by EV charging.
- Similar to the case with single phase service transformer, the remote secondary network suffers larger voltage drop than the nearby secondary network. The magnitude of voltage drop in each network is compared in Table 6.1-2.

Load nodes in the secondary network	**Service transformer remote from the substation**	**Service transformer nearby the substation**
	Largest voltage drop	Largest voltage drop
Load node with one EV	0.68 V (0.54%)	0.15 V (0.123%)
Load nodes without EV, but the EV charging current path	0.45 V (0.37 %)	0.046 V (0.037%)

Table 6.1-2: Effects of location of the three phase service transformer with respect to the substation for a mixed (residential and commercial) circuit

Chapter 7: Evaluation of voltage variations on the primary networks

Effects of distance of the secondary network from the substation on the voltage variation of the primary wires are evaluated and compared in this section. Two different charging scenarios are simulated by varying the location of the service transformer with respect to the substation as mentioned in Table 7-1.

Circuit parameters under evaluation	**Different conditions evaluated for**	**Condition for the largest voltage drop**
Location of the service transformer w.r.t the substation	Remote from the substation	Service transformer remote from the substation
	Nearby the substation	

Table 7-1: Circuit parameters evaluated for their impact on the primary network

A single-phase distribution transformer with typical kVA rating from 15 kVA to 50 kVA serving a secondary network is selected for the study. The secondary network under evaluation is assigned four240V/16A EV charging station at the distant load nodes from the service transformer. The voltage variations on the primary feeder supplying for the service transformer are evaluated and compared for both cases. The evaluation is done for both residential and mixed distribution circuits. Table 7-2 summarizes the evaluation conditions.

It should be noted that the EV charging stations in this case are assumed to be charging multiple EV loads sequentially from 6 pm to 8 am. The charging profile for the EV charging station is shown in Fig. 4.4-2.

Evaluation parameters				
Location of service transformer	*Circuit type*	*Charging Station*	*Location of EV w.r.t. the service transformer*	*Number of EVs in the secondary circuit*
Remote vs. Nearby	Residential	240V/16A	Remote	Four
Remote vs. Nearby	Mix	240V/16A	Remote	Four

Table 7-2: Parameters to evaluate effects of location of the service transformer

Based on the analysis, the following observations are made:

- A primary network supplying for a secondary network farther out from the substation tends to have lower voltage magnitudes than those nearby the substation. This phenomenon is true for both residential and mixed distribution circuits.
- For both types of circuits, the largest voltage drop in the primary wire occurs when the service transformer is remote from the substation and is approximately 0.12% and 0.02% for residential and mixed distribution circuit, respectively.

7.1 Effects of Location of the Service Transformer with Respect to the Substation on the Primary Network for a Residential Circuit

To determine the effects of location of the service transformer on the voltage profile of the primary network, voltage magnitude at the primary node of the service transformer is recorded. For this purpose, two transformers are chosen: one remote from the substation and one nearby. The characteristics of the secondary networks served by these two transformers are summarized below (Table 7.1-1).

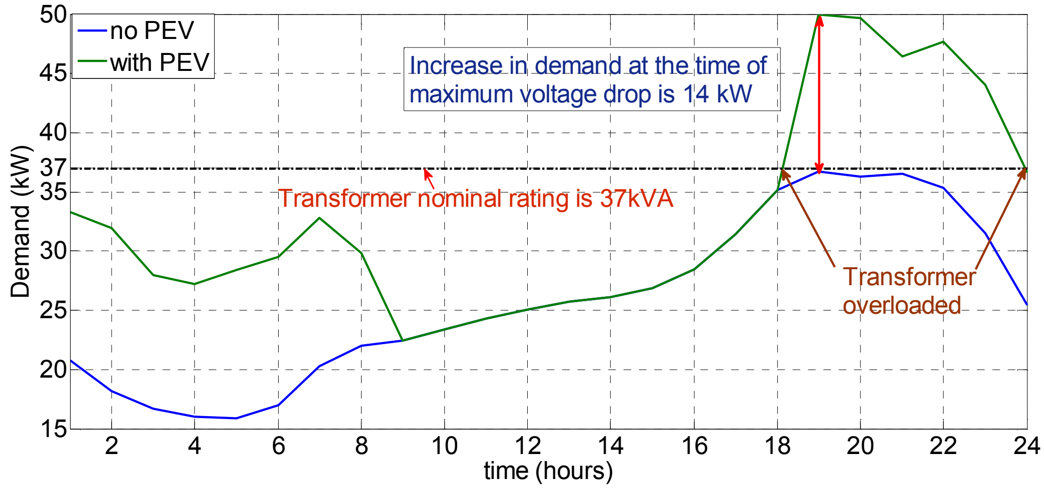
Service transformer location	Rating of transformer	Number of loads	Maximum load demand (no EV loads)	Maximum load demand (with EV loads)	Number of EV loads
Remote	37 kVA	8	36.6 kW	50 kW (overloading)	Four
Nearby	50 kVA	4	15.2 kW	29 kW	Four

Table 7.1-1: Characteristics of the secondary networks under evaluation

Fig. 7.1-1 shows hourly load demand for the two service transformers (remote/nearby), with and without EV loads. Since time of operation of the EV charging station is chosen from 6 pm to 8 am, an increase in the kW demand is recorded for that time period only. A transformer overloading during peak demand hours is recorded for the case when the service transformer is remote from the substation. However no such overloading is recorded when the service transformer is nearby the substation.

For both cases, the largest voltage drop in the primary wire corresponds to the maximum increase in kW demand (i.e. 14 kW). Although the charging stations are assumed to be charging multiple EV loads sequentially, at an instant only one electric vehicle is getting charged by one EV charging station. Hence, at any instant the maximum increase in the kW demand as seen by the secondary network does not exceed 14 kW (which corresponds to the kW demand for four electric vehicles).

Since EV charging station is assumed to be charging multiple EV loads sequentially, an increase in kW demand and a voltage drop is recorded from 6 pm to 8 am.



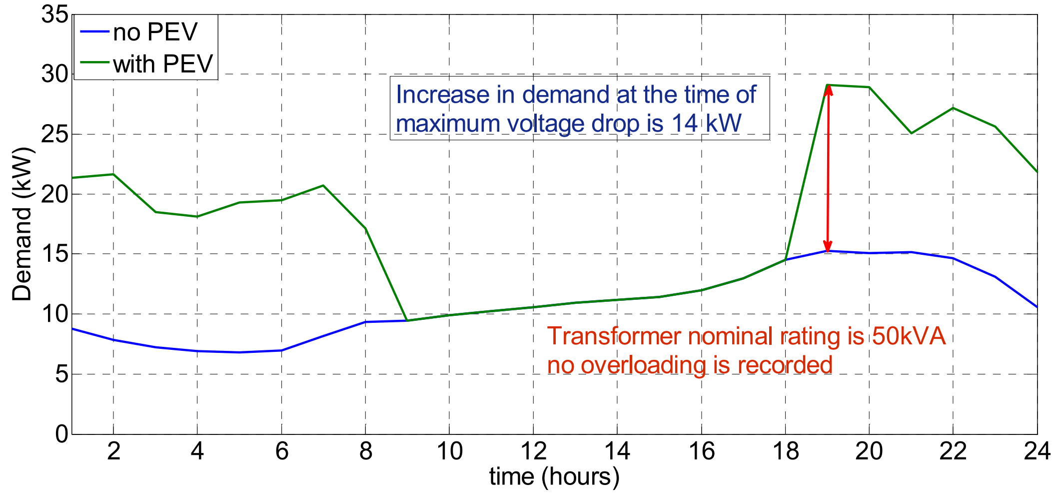


Fig. 7.1-1: Load shape profiles, with and without an EV load for the residential circuit. The service transformer is (a) distant from the substation and (b) nearby the substation

Fig. 7.1-2 shows the voltage variations recorded for the primary wire for both locations of the service transformer. During normal operating conditions, the largest voltage drop recorded for remote and nearby service transformers is about 0.12% and 0.017%, respectively. Clearly, the percentage voltage drop in the primary feeder for both cases is very small.

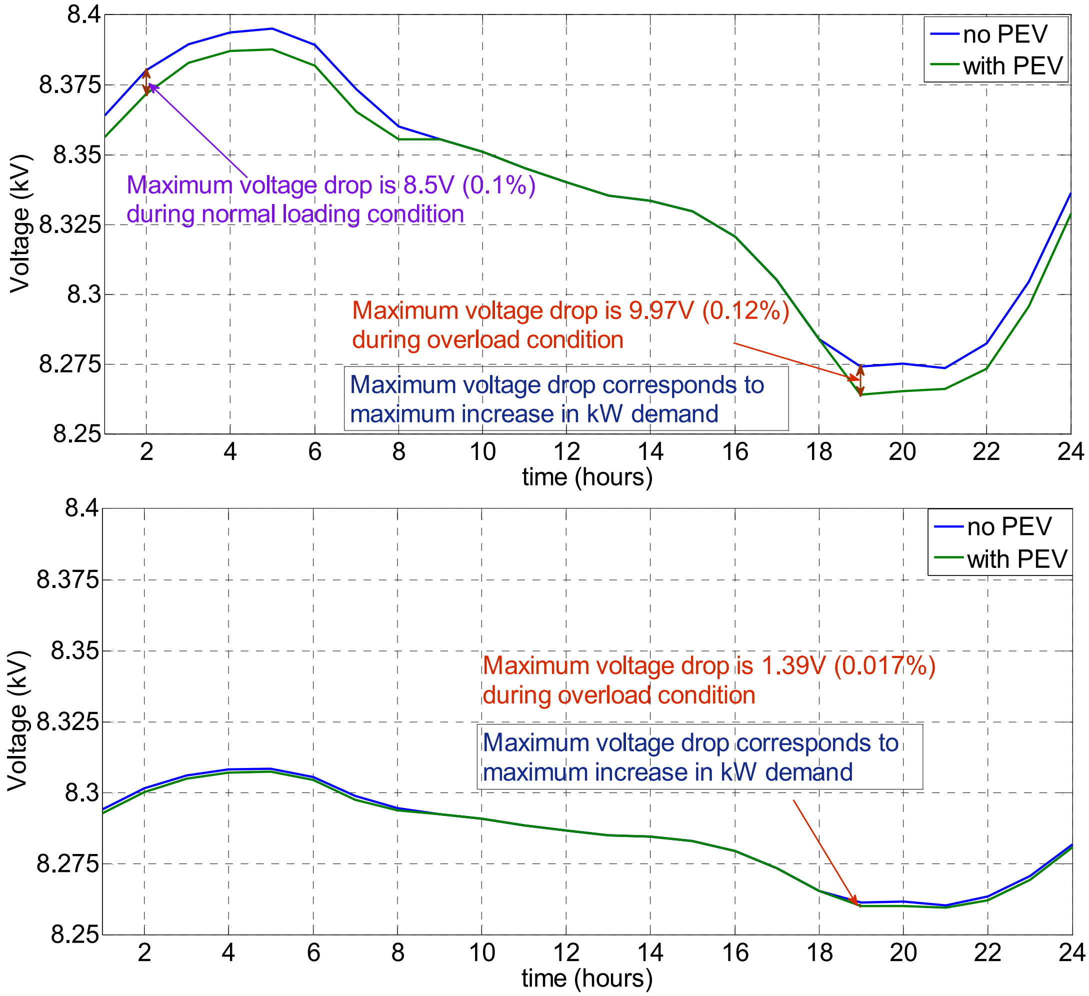


Fig.7.1-2: Largest voltage drop recorded in the primary wires for the residential circuit. The service transformer is (a) remote from the substation and (b) nearby the substation

Comparing the voltage drops in the primary wire for locations of the service transformer, the following observations are made:

- The effect on voltage variation of the primary network due to EV charging is minimal.
- The primary wire serving for a remote secondary network suffers a larger voltage drop than the primary wire serving for a nearby service transformer.

- The voltage drop on the primary of the service transformer for a remote secondary network is 0.12 %. However for a nearby secondary network the voltage drop on the primary wire decreases to 0.017%.

7.2 Effects of Location of the Service Transformer with respect to the Substation on the Primary Network for a Mixed Circuit

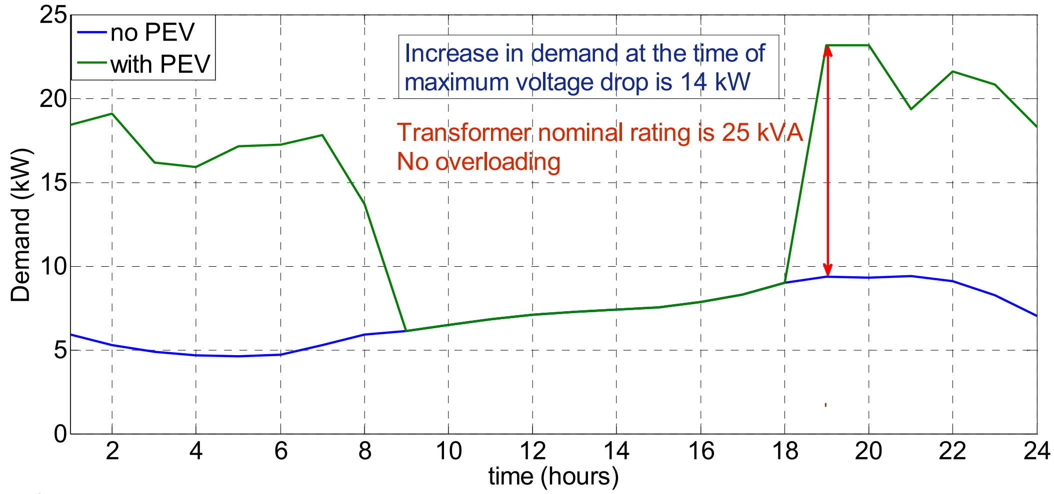
A similar analysis is done for a mixed distribution circuit, which consists of both residential and commercial loads. Two different service transformers are chosen; one remote from the substation and one nearby. It should be noted that both transformers chosen for the analysis here are serving residential loads. The characteristics of the secondary networks served by these two transformers are summarized below.

Service transformer location	Rating of transformer	Number of loads	Maximum load demand (no EV load)	Maximum load demand (with EV load)	Number of EV loads
Remote	25 kVA	6	9.4 kW	23 kW	Four
Nearby	25 kVA	6	8.7 kW	22.5 kW	Four

Table 7.2-1: Characteristics of the secondary networks under evaluation

Fig. 7.2-1 shows hourly load demand for the two locations of the service transformers (remote/nearby). An increase in the kW demand is recorded when the EV load is charging. No overloading of the service transformers is recorded for either case.

Similar to residential circuit, the EV charging stations in this case are also assumed to be charging multiple EVs, sequentially. Hence, a voltage drop in the secondary network is seen for this duration.



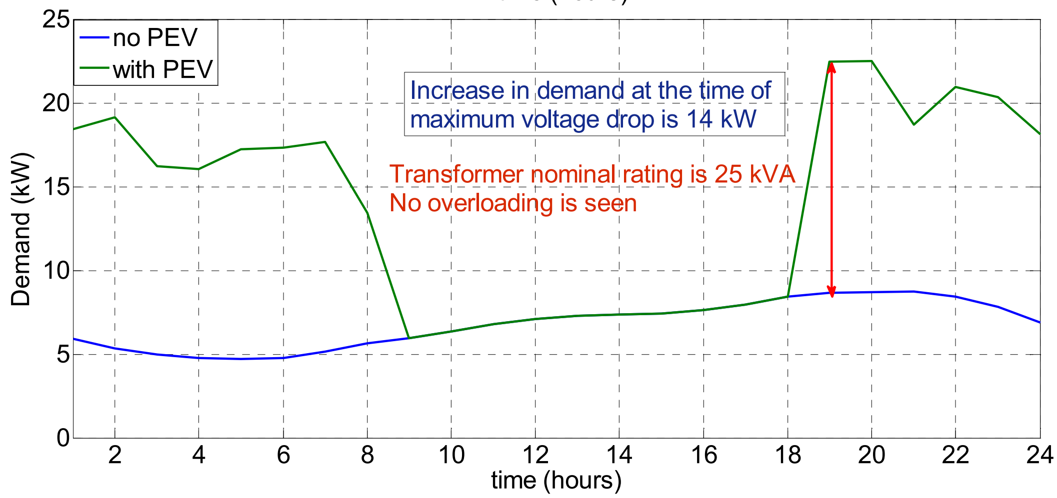


Fig. 7.2-1: Load shape profiles, with and without an EV load for the mixed distribution circuit. The service transformer is (a) distant from the substation and (b) nearby the substation

The largest voltage variations in the primary of the service transformer for both locations of the service transformer are shown in Fig. 7.2-2. The largest voltage drop of about 0.02% and 0.005% are recorded for the remote and nearby service transformers, respectively. For either case, the largest drop in primary wire voltage is very small.

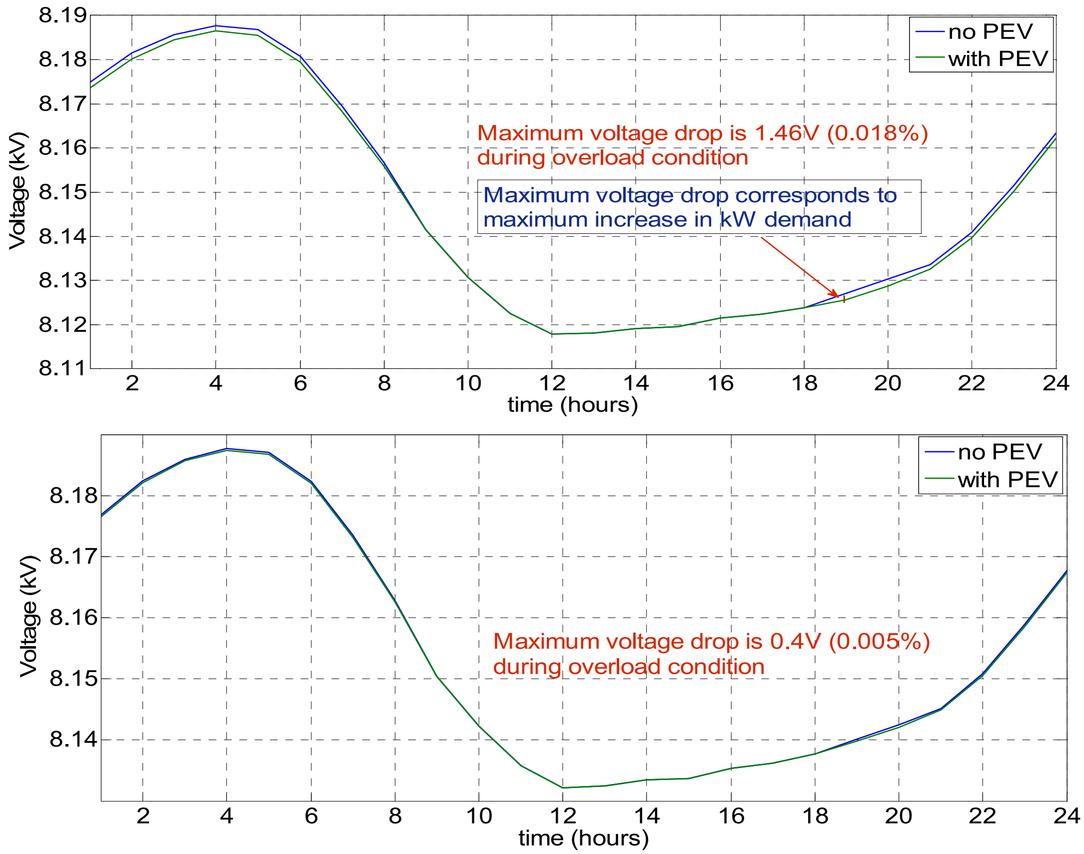


Fig.7.2-2: Largest voltage drop recorded in the primary wires for the mixed distribution circuit. The service transformer is (a) remote from the substation and (b) nearby the substation

A comparison for the voltage variation in both locations of the secondary networks due to EV charging is drawn and the following observations are made:

- The effect on voltage variation of the primary wire due to EV charging is minimal for both cases (remote/nearby).
- The primary network for the remote service transformer suffers larger voltage drops than the nearby service transformer.
- The voltage drop on the primary of the service transformer for a remote secondary network is 0.02 %. However for a nearby secondary network the voltage drop decreases to 0.005%.

7.3 SUMMARY FOR THE EFFECT OF LOCATION OF THE SERVICE TRANSFORMER WITH RESPECT TO THE SUBSTATION ON THE PRIMARY NETWORK

This study concludes that the primary wires supplying for a distant secondary network experience larger voltage drop due to EV load charging. The conclusions drawn are consistent for both types of distribution circuits, residential and mixed. Based on the observations made in Section 7.1 and 7.2, the following conclusions are drawn.

- For both circuits, the largest voltage drop is recorded when the service transformer is remote from the substation and it is approximately 0.12% and 0.02% for residential and mixed distribution circuits, respectively.
- The largest voltage drop for the mixed distribution feeder (0.02%) is much less than the largest voltage drop for the residential feeder (0.12%). The difference could be attributed to a larger span of the residential network.
- For both circuits, the largest voltage drop decreases when the secondary network considered is close to the substation.

Observations drawn from the study	**Residential circuit**		**Mix (residential and commercial) circuit**	
Largest voltage drop noted in the primary of the service transformer	Service transformer is		Service transformer is	
	Remote	Nearby	Remote	Nearby
	0.12%	0.017%	0.018%	0.005%
Location of Service transformer for the largest voltage drop	Remote from the substation		Remote from the substation	

Table 7.3-1: Summary for the effects of location of the service transformer with respect to the substation

Chapter 8: Summary of the Voltage Variation Study

Various factors affecting the voltage quality of the distribution feeder, due to EV loads are evaluated and compared in this report. Several realistic charging scenarios for a residential and a mixed distribution feeder are simulated. The charging scenarios are then evaluated and compared for the potential factors that could significantly affect the distribution network voltage quality. A summary of the voltage variation study is presented in this chapter.

8.1 EFFECTS OF LOCATION OF THE SERVICE TRANSFORMER WITH RESPECT TO THE SUBSTATION

As the distance of the service transformer from the substation increases, voltage variations in the secondary network also increase. Voltage drop is more for a distant service transformer than a nearby service transformer. Table 8.1-1 presents a comparison for both distribution circuits considered in the study, i.e. residential and mixed circuit.

Type of the transformer	**Effect on the secondary voltage**	**Type of the circuit**	**Largest Voltage Drop**	
			Transformer distant from the substation	**Transformer close to the substation**
Single phase service transformer	EV load nodes and node in the path of EV load	Residential	1.5%.	1.03%.
		Mixed	1.5%.	1%.
	Load nodes not in the path of EV loads	Residential	< 0.125%.	< 0.12%.
		Mixed	< 0.07%.	< 0.07%.
Three phase transformer	EV load nodes	Mixed	< 0.6%.	< 0.2%.

Table 8.1-1: Effect of location of the service transformer with respect to the substation on the voltage profile of the secondary network

8.2 Effects of Location of EV Chargers with respect to the Service Transformer

In this case, the service transformer is taken distant from the substation. A comparison is drawn for different locations of the EV load (remote/nearby) with respect to the service transformer. As expected voltage drop is comparatively greater when an EV load is far from the service transformer. A detailed comparison for the two circuits is shown is Table 8.2-1.

Effect on the secondary voltage	**Type of the circuit**	**Largest Voltage Drop**	
		EV load remote from the service transformer	**EV load nearby the service transformer**
EV load nodes and node in the path of EV load	Residential	1.5%.	0.75%.
	Mixed	1.5%.	0.123%.
Load nodes not in the path of EV loads	Residential	< 0.122%.	< 0.1%.
	Mixed	< 0.07%.	< 0.07%.

Table 8.2-1: Effect of location of the EV load with respect to the service transformer on the voltage profile of the secondary network

8.3 Size of EV Charging Station (240V/16A or 240V/30A)

The voltage quality effects of two different size of EV charging station are evaluated and compared. For the evaluation an EV station is located at the farthest load node. As expected voltage drop is worse for the EV load type: 240V/30A. Table 8.3-1 presents the comparison for the two types of EV load.

Effect on the secondary voltage	Type of the circuit	Largest Voltage Drop	
		EV load type : 240V/16A	**EV load type : 240V/30A**
EV load nodes and node in the path of EV load	Residential	1.5%.	2.6%.
	Mixed	1.5%.	2.8%.
Load nodes not in the path of EV loads	Residential	< 0.125%.	< 0.25%.
	Mixed	< 0.07%.	< 0.14%.

Table 8.3-1: Effect of size of the EV load charging station on the voltage profile of the secondary network

8.4 Effects of an Additional EV Charging Station added adjacent to an Existing EV Load

Adding an additional EV load adjacent to an existing EV charging station increases the voltage drop in the secondary network. A comparison is drawn in Table 8.4-1 for both distribution circuits.

Effect on the secondary voltage	Type of the circuit	Largest Voltage Drop for	
		One EV load	**One + One EV load**
EV load nodes and node in the path of EV load	Residential	1.5%	2.8%
	Mixed	1.5%	1.8%
Load nodes not in the path of EV loads	Residential	0.12%	0.24%
	Mixed	0.07%	0.14%

Table 8.4-1: Effect of adding an additional EV charging station adjacent to an existing EV load for both distribution circuits

8.5 EFFECTS OF LOCATION OF THE SECONDARY NETWORK ON THE VOLTAGE VARIATION OF THE PRIMARY NETWORK

In this case the effects of EV loads on the primary wires are evaluated. The voltage drop on the primary of the service transformer due to EV charging is recorded. Two cases are simulated: one with the secondary network far from the substation and other with the secondary network nearby the substation. The study shows that the primary wires are not as much affected by the EV loads as the secondary networks. Also a secondary network distant from the substation causes more voltage drop in the primary wire than a secondary network close to the substation.

Effect on the primary voltage	**Type of the circuit**	**Largest Voltage Drop for**	
		Secondary network is distant from the substation	**Secondary network is close to the substation**
At the primary wire of the service transformer	Residential circuit	0.12%.	0.017%.
	Mixed circuit	0.018%.	0.005%.

Table 8.5-1: Effect of location of the secondary network on the voltage variation of the primary wires for both distribution circuits

Appendix

VISUAL BASIC CODE

```
-----------------------------------------------------------------------------------------------------
Option Compare Database
-----------------------------------------------------------------------------------------------------

Public Sub runall()
    MakeMaster
    MakeLoadsFile
    MakeLine
    MakeLineCodes
    MakeCapacitors
    MakeTransformers
    MakePEVLoadsFile
  ' MakeTransformerCode
    MakeBusCoords
End Sub

-----------------------------------------------------------------------------------------------------

Function RemoveBlanks(ByVal S As String) As String
    Dim pos As Long
        pos = InStr(1, S, " ")
    Do While pos > 0
        S = Left(S, pos - 1) + "_" + Mid(S, pos + 1)
        pos = InStr(1, S, " ")
    Loop
        RemoveBlanks = S
End Function

-----------------------------------------------------------------------------------------------------

Function ReplacePeriods(ByVal S As String) As String
    Dim pos As Long
        pos = InStr(1, S, ".")
    Do While pos > 0
        S = Left(S, pos - 1) + "-" + Mid(S, pos + 1)
        pos = InStr(1, S, ".")
    Loop
        ReplacePeriods = S
End Function

-----------------------------------------------------------------------------------------------------

Public Sub MakeMaster()

Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
files\June_loadAllc\DSS_modified\Master.dss" For Output As #1

Print #1, "Clear"
```

```
Print #1, "New Circuit.JUNE_JUNE Bus1=CB_17 pu=1.029 r1=0.029518 x1=0.483908 r0=0.027423
x0=1.302895 basekv=13.8 "
   Print #1, " "
   Print #1, "Redirect LineCodes.dss"
   Print #1, "Redirect Lines.dss"
   'Print #1, "Redirect TransformerCodes.dss"
   Print #1, "Redirect Transformers.dss"
   Print #1, "Redirect Loads.dss"
   Print #1, "Redirect Capacitors.dss"
   Print #1, "Set voltagebases = [13.8, 4.16, 2.4, 0.24]"
   Print #1, "CalcVoltageBases"

   Close #1

End Sub
```

```
Public Sub MakeLoadsFile()

Dim LoadTable As DAO.Recordset
Dim SectID As String
Dim TestCase As Integer
Dim Kvol As String

Set LoadTable = CurrentDb.OpenRecordset("Loads", dbOpenDynaset)

Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
files\June_loadAllc\DSS_centerTap\Loads.dss" For Output As #1

LoadTable.MoveFirst
Do While Not LoadTable.EOF

  Select Case LoadTable!Phase

   Case "A"
   connection = ".1"
   phased = "1"
   Case "B"
   connection = ".2"
   phased = "1"
   Case "C"
   connection = ".3"
   phased = "1"
   Case "ABC"
   connection = ".1.2.3"
   phased = "3"
   End Select

   mon_KWH = CDbl(LoadTable!KWH) * 30
```

```
Select Case LoadTable!KVLL

        Case "13.8"
            If Format(LoadTable!Value1 * LoadTable!Value2 / 100) = "0" Then
                Print #1, "!";
            End If

Print #1, "New Load." + LoadTable!CustomerNumber + "_" + LoadTable!Phase + " Bus1=" +
ReplacePeriods(LoadTable!ToNodeID) + connection;
Print #1, " Phases=" + phased + " Conn=wye" + " Model=1";
Print #1, " kV=" + CStr(Round(13.8 / 1.7321, 4));
Print #1, " kW=" + LoadTable!Value1;
Print #1, " PF=" + CStr(CDbl(LoadTable!Value2 / 100));

        Select Case mon_KWH
                Case Is < 500
                    Print #1, " daily=R1";
                Case Is < 1000
                    Print #1, " daily=R2";
                Case Is < 1500
                    Print #1, " daily=R3";
                Case Is < 2000
                    Print #1, " daily=R4";
                Case Is < 6000
                    Print #1, " daily=RT3";
                Case Is < 8400
                    Print #1, " daily=GS4";
                Case Is < 10000
                    Print #1, " daily=GST1";
                Case Is < 18000
                    Print #1, " daily=GS5";
                Case Is < 50000
                    Print #1, " daily=GST2";
                Case Is < 100000
                    Print #1, " daily=LPT1";
                Case Is < 223980
                    Print #1, " daily=LPT2";
                Case Else
                    Print #1, " daily=LPT3";
       End Select

Print #1, " NumCust=" + LoadTable!NumberOfCustomer

        Case "4.16"

            If Format(LoadTable!Value1 * LoadTable!Value2 / 100) = "0" Then
                Print #1, "!";
            End If

Print #1, "New Load." + LoadTable!CustomerNumber + "_" + LoadTable!Phase + " Bus1=" +
ReplacePeriods(LoadTable!ToNodeID) + connection;
Print #1, " Phases=" + phased + " Conn=wye" + " Model=1";
```

```
Print #1, " kV=" + CStr(Round(4.16 / 1.7321, 4));
Print #1, " kW=" + LoadTable!Value1;
Print #1, " PF=" + CStr(CDbl(LoadTable!Value2 / 100));

   Select Case mon_KWH
        Case Is < 500
          Print #1, " daily=R1";
        Case Is < 1000
          Print #1, " daily=R2";
        Case Is < 1500
          Print #1, " daily=R3";
        Case Is < 2000
          Print #1, " daily=R4";
        Case Is < 6000
          Print #1, " daily=RT3";
        Case Is < 8400
          Print #1, " daily=GS4";
        Case Is < 10000
          Print #1, " daily=GST1";
        Case Is < 18000
          Print #1, " daily=GS5";
        Case Is < 50000
          Print #1, " daily=GST2";
        Case Is < 100000
          Print #1, " daily=LPT1";
        Case Is < 223980
          Print #1, " daily=LPT2";
        Case Else
          Print #1, " daily=LPT3";
   End Select
      Print #1, " NumCust=" + LoadTable!NumberOfCustomer

    Case "0.48"
      If Format(LoadTable!Value1 * LoadTable!Value2 / 100) = "0" Then
        Print #1, "!";
      End If

Print #1, "New Load." + LoadTable!CustomerNumber + "_" + LoadTable!Phase + " Bus1=" +
ReplacePeriods(LoadTable!ToNodeID) + connection;
Print #1, " Phases=" + phased + " Conn=wye" + " Model=1";
Print #1, " kV=" + CStr(Round(0.48 / 1.7321, 4));
Print #1, " kW=" + LoadTable!Value1;
Print #1, " PF=" + CStr(CDbl(LoadTable!Value2 / 100));

   Select Case mon_KWH
        Case Is < 500
          Print #1, " daily=R1";
        Case Is < 1000
          Print #1, " daily=R2";
        Case Is < 1500
          Print #1, " daily=R3";
        Case Is < 2000
```

```
            Print #1, " daily=R4";
          Case Is < 6000
            Print #1, " daily=RT3";
          Case Is < 8400
            Print #1, " daily=GS4";
          Case Is < 10000
            Print #1, " daily=GST1";
          Case Is < 18000
            Print #1, " daily=GS5";
          Case Is < 50000
            Print #1, " daily=GST2";
          Case Is < 100000
            Print #1, " daily=LPT1";
          Case Is < 223980
            Print #1, " daily=LPT2";
          Case Else
            Print #1, " daily=LPT3";
   End Select

Print #1, " NumCust=" + LoadTable!NumberOfCustomer

      Case "0.208"
        If Format(LoadTable!Value1 * LoadTable!Value2 / 100) = "0" Then
          Print #1, "!";
        End If

Print #1, "New Load." + LoadTable!CustomerNumber + "_" + LoadTable!Phase + " Bus1=" +
ReplacePeriods(LoadTable!ToNodeID) + connection;
Print #1, " Phases=" + phased + " Conn=wye" + " Model=1";
Print #1, " kV=" + CStr(Round(0.208 / 1.7321, 4));
Print #1, " kW=" + LoadTable!Value1;
Print #1, " PF=" + CStr(CDbl(LoadTable!Value2 / 100));

   Select Case mon_KWH
          Case Is < 500
            Print #1, " daily=R1";
          Case Is < 1000
            Print #1, " daily=R2";
          Case Is < 1500
            Print #1, " daily=R3";
          Case Is < 2000
            Print #1, " daily=R4";
          Case Is < 6000
            Print #1, " daily=RT3";
          Case Is < 8400
            Print #1, " daily=GS4";
          Case Is < 10000
            Print #1, " daily=GST1";
          Case Is < 18000
            Print #1, " daily=GS5";
          Case Is < 50000
            Print #1, " daily=GST2";
```

```
            Case Is < 100000
               Print #1, " daily=LPT1";
            Case Is < 223980
               Print #1, " daily=LPT2";
            Case Else
               Print #1, " daily=LPT3";
   End Select
Print #1, " NumCust=" + LoadTable!NumberOfCustomer

    Case Else

          If Format(LoadTable!Value1 * LoadTable!Value2 / 100) = "0" Then
             Print #1, "!";
          End If

Print #1, "New Load." + LoadTable!CustomerNumber + "_" + LoadTable!Phase + "-1" + " Bus1=" +
ReplacePeriods(LoadTable!ToNodeID) + ".1.0";
Print #1, " Phases=" + "1" + " Conn=wye" + " Model=1";
Print #1, " kV=0.12";
Print #1, " kW=" + CStr(Round(LoadTable!Value1 / 2, 4));
Print #1, " PF=" + CStr(CDbl(LoadTable!Value2 / 100));

     Select Case mon_KWH
            Case Is < 500
               Print #1, " daily=R1";
            Case Is < 1000
               Print #1, " daily=R2";
            Case Is < 1500
               Print #1, " daily=R3";
            Case Is < 2000
               Print #1, " daily=R4";
            Case Is < 6000
               Print #1, " daily=RT3";
            Case Is < 8400
               Print #1, " daily=GS4";
            Case Is < 10000
               Print #1, " daily=GST1";
            Case Is < 18000
               Print #1, " daily=GS5";
            Case Is < 50000
               Print #1, " daily=GST2";
            Case Is < 100000
               Print #1, " daily=LPT1";
            Case Is < 223980
               Print #1, " daily=LPT2";
            Case Else
               Print #1, " daily=LPT3";
      End Select

          Print #1, " NumCust=" + LoadTable!NumberOfCustomer

          If Format(LoadTable!Value1 * LoadTable!Value2 / 100) = "0" Then
```

```
            Print #1, "!";
        End If

Print #1, "New Load." + LoadTable!CustomerNumber + "_" + LoadTable!Phase + "-2" + " Bus1=" +
ReplacePeriods(LoadTable!ToNodeID) + ".2.0";
Print #1, " Phases=" + "1" + " Conn=wye" + " Model=1";
Print #1, " kV=0.12";
Print #1, " kW=" + CStr(Round(LoadTable!Value1 / 2, 4));
Print #1, " PF=" + CStr(CDbl(LoadTable!Value2 / 100));

    Select Case mon_KWH
        Case Is < 500
            Print #1, " daily=R1";
        Case Is < 1000
            Print #1, " daily=R2";
        Case Is < 1500
            Print #1, " daily=R3";
        Case Is < 2000
            Print #1, " daily=R4";
        Case Is < 6000
            Print #1, " daily=RT3";
        Case Is < 8400
            Print #1, " daily=GS4";
        Case Is < 10000
            Print #1, " daily=GST1";
        Case Is < 18000
            Print #1, " daily=GS5";
        Case Is < 50000
            Print #1, " daily=GST2";
        Case Is < 100000
            Print #1, " daily=LPT1";
        Case Is < 223980
            Print #1, " daily=LPT2";
        Case Else
            Print #1, " daily=LPT3";
    End Select          'Print #1, " Daily=" + "Default";
Print #1, " NumCust=" + LoadTable!NumberOfCustomer

End Select

   LoadTable.MoveNext
 Loop

 Close #1

End Sub

-----------------------------------------------------------------------------------------------------------

Public Sub MakePEVLoadsFile()

Dim PevLoadTable As DAO.Recordset
```

```
Dim SectID As String
Dim TestCase As Integer
Dim Kvol As String

Set PevLoadTable = CurrentDb.OpenRecordset("Loads", dbOpenDynaset)

Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
files\June_loadAllc\DSS_modified\PEVLoads.dss" For Output As #1

PevLoadTable.MoveFirst
Do While Not PevLoadTable.EOF

   Select Case PevLoadTable!KVLL
      Case "13.6"
      Case "4.16"
      Case "0.48"
      Case "0.208"
      Case Else
         If Format(PevLoadTable!Value1 * PevLoadTable!Value2 / 100) = "0" Then
         Else
Print #1, "New Load." + "pev" + PevLoadTable!CustomerNumber + "_" + PevLoadTable!Phase + "
Bus1=" + ReplacePeriods(PevLoadTable!ToNodeID) + ".1.2";
Print #1, " Phases=" + "1" + " Conn=wye" + " Model=5";
Print #1, " kV=0.24";
Print #1, " kW=" + "7.2";
Print #1, " PF=" + "1";
Print #1, " Daily=" + "lshape240-30";
Print #1, " NumCust=" + PevLoadTable!NumberOfCustomer
         End If

   End Select

   PevLoadTable.MoveNext
 Loop
 Close #1

End Sub
----------------------------------------------------------------------------------------------------------

Public Sub MakeLine()

   Set Line = CurrentDb.OpenRecordset("Line", dbOpenTable)
   Set Switch1 = CurrentDb.OpenRecordset("Switch", dbOpenDynaset) 'read in switch table

   Dim connection As String
   Dim phased As String
   Dim temp As String
   Dim IDlen As Integer
   Dim ownID As String
```

```
Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
        files\June_loadAllc\DSS_modified\Lines.dss" For Output As #1

Line.MoveFirst
Do While Not Line.EOF
Select Case Line!Phase
Case "ABC"
   connection = ".1.2.3"
   phased = "3"
Case "A"
   connection = ".1"
   phased = "1"
Case "B"
   connection = ".2"
   phased = "1"
Case "C"
   connection = ".3"
   phased = "1"
Case "AB"
   connection = ".1.2"
   phased = "2"
Case "AC"
   connection = ".1.3"
   phased = "2"
Case "BC"
   connection = ".2.3"
   phased = "2"
Case Else
   connection = "ERROR"
   phased = "ERROR"
End Select

If Line!Length = 0 Then
   Llen = 0.01  ' Changed to smaller value - JT
Else
   Llen = Line!Length
End If


IDlen = Len(Line!OwnerID)
If IDlen = 4 Then
   ownID = Right(Line!OwnerID, 0)
Else
   ownID = Right(Line!OwnerID, IDlen - 5)
End If


If ownID = "" Or ownID = "6310" Or ownID = "6512" Or ownID = "6276" Or ownID = "14081" Or
ownID = "6387" Or ownID = "6273" Or ownID = "121650" Or ownID = "6516" Or ownID = "14047" Or
ownID = "6315" Or ownID = "5129" Or ownID = "253475" Or ownID = "6285" Or ownID = "6364" Or
ownID = "5209" Or ownID = "6347" Or ownID = "420867" Or ownID = "5706" Or ownID = "6345" Or
ownID = "6286" Or ownID = "14041" Then
```

```
    LineCode_ID = ReplacePeriods(Line!LineID)
    Print #1, "New Line." + Left(Line!LineID, 2) + "_" + Line!SectionID;
    Print #1, " Bus1=" + ReplacePeriods(Line!FromNodeID) + connection; ' added in connection phasing
    Print #1, " Bus2=" + ReplacePeriods(Line!ToNodeID) + connection;
    Print #1, " Linecode=" + LineCode_ID;
    Print #1, " Length=" + CStr(Llen);
    Print #1, " Phases=" + phased;

' add logic to seach for switch --> status

    temp = "[SectionID] LIKE '" + Line!SectionID + "'"
    Switch1.MoveFirst
    Switch1.FindFirst temp
    If Switch1.NoMatch Then
       Print #1, " enabled=True";
       Print #1, " Switch=False";
    Else
       If Switch1.NormalStatus = "Open" Then
          Print #1, " enabled=False";
          Print #1, " Switch=True";
       Else
          Print #1, " enabled=True";
          Print #1, " Switch=False";
       End If
    End If

    Print #1, " Units=m" ' changed to meters

Else

    LineCode_ID = ReplacePeriods(Line!LineID)
    Print #1, "New Line." + Left(Line!LineID, 2) + "_" + Line!SectionID;
    Print #1, " Bus1=" + ReplacePeriods(Line!FromNodeID) + ".1"; ' added in connection phasing
    Print #1, " Bus2=" + ReplacePeriods(Line!ToNodeID) + ".1";
    Print #1, " Linecode=" + LineCode_ID;
    Print #1, " Length=" + CStr(Llen);
    Print #1, " Phases=" + "1";

' add logic to seach for switch --> status

    temp = "[SectionID] LIKE '" + Line!SectionID + "'"
    Switch1.MoveFirst
    Switch1.FindFirst temp
    If Switch1.NoMatch Then
       Print #1, " enabled=True";
       Print #1, " Switch=False";
    Else
       If Switch1.NormalStatus = "Open" Then
          Print #1, " enabled=False";
          Print #1, " Switch=True";
       Else
```

```
            Print #1, " enabled=True";
            Print #1, " Switch=False";
         End If
      End If

      Print #1, " Units=m" ' changed to meters


      Print #1, "New Line." + Left(Line!LineID, 2) + "_" + Line!SectionID + "-1";
      Print #1, " Bus1=" + ReplacePeriods(Line!FromNodeID) + ".2"; ' added in connection phasing
      Print #1, " Bus2=" + ReplacePeriods(Line!ToNodeID) + ".2";
      Print #1, " Linecode=" + LineCode_ID;
      Print #1, " Length=" + CStr(Llen);
      Print #1, " Phases=" + "1";

   ' add logic to seach for switch --> status

      temp = "[SectionID] LIKE '" + Line!SectionID + "'"
      Switch1.MoveFirst
      Switch1.FindFirst temp
      If Switch1.NoMatch Then
         Print #1, " enabled=True";
         Print #1, " Switch=False";
      Else
         If Switch1.NormalStatus = "Open" Then
            Print #1, " enabled=False";
            Print #1, " Switch=True";
         Else
            Print #1, " enabled=True";
            Print #1, " Switch=False";
         End If
      End If

      Print #1, " Units=m" ' changed to meters


   End If
      Line.MoveNext

   Loop
   Close #1
End Sub
```

```
Public Sub MakeLineCodes()

Set OverheadLineCodes = CurrentDb.OpenRecordset("OverheadLineCodes", dbOpenTable)

Set CableCodes = CurrentDb.OpenRecordset("CableCodes", dbOpenTable)
```

```
Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
files\June_loadAllc\DSS_modified\LineCodes.dss" For Output As #1

Dim MinRating As Double

   Print #1, "! Overhead line codes"
   OverheadLineCodes.MoveFirst

   Do While Not OverheadLineCodes.EOF
      OHLineCode_ID = ReplacePeriods(OverheadLineCodes!EquipmentID)
      Print #1, "New Linecode." + OHLineCode_ID;
      Print #1, " Nphases=3";
      Print #1, " R1=" + OverheadLineCodes!PositiveSequenceResistance;
      Print #1, " X1=" + OverheadLineCodes!PositiveSequenceReactance;
      Print #1, " R0=" + OverheadLineCodes!ZeroSequenceResistance;
      Print #1, " X0=" + OverheadLineCodes!ZeroSequenceReactance;
      Print #1, " C1=" + CStr(Round(CDbl(OverheadLineCodes!PositiveSequenceShuntSusceptance) /
          (376.99111 * 1000), 10));
      Print #1, " C0=" + CStr(Round(CDbl(OverheadLineCodes!ZeroSequenceShuntSusceptance) /
          (376.99111 * 1000), 10));
      Print #1, " Units=km baseFreq=60";
      Print #1, " Normamps=" + OverheadLineCodes!FirstRating;
      Print #1, " Emergamps=" + OverheadLineCodes!SecondRating

      OverheadLineCodes.MoveNext
   Loop

   Print #1, " "
   Print #1, "! Cable line codes"
   CableCodes.MoveFirst
   Do While Not CableCodes.EOF
      UGLineCode_ID = ReplacePeriods(CableCodes!EquipmentID)
      Print #1, "New Linecode." + UGLineCode_ID;
      Print #1, " Nphases=3";
      Print #1, " R1=" + CableCodes!PositiveSequenceResistance;
      Print #1, " X1=" + CableCodes!PositiveSequenceReactance;
      Print #1, " R0=" + CableCodes!ZeroSequenceResistance;
      Print #1, " X0=" + CableCodes!ZeroSequenceReactance;
      Print #1, " C1=" + CStr(Round(CDbl(CableCodes!PositiveSequenceShuntSusceptance) / (376.99111 *
          1000), 10));
      Print #1, " C0=" + CStr(Round(CDbl(CableCodes!ZeroSequenceShuntSusceptance) / (376.99111 *
          1000), 10));
      Print #1, " Units=km BaseFreq=60";
      Print #1, " Normamps=" + CableCodes!FirstRating;
      Print #1, " Emergamps=" + CableCodes!SecondRating

      CableCodes.MoveNext
   Loop

   Close #1
End Sub
```

Public Sub MakeCapacitors()

```
    Set ShuntCapacitor = CurrentDb.OpenRecordset("ShuntCapacitor", dbOpenTable)

    Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
            files\June_loadAllc\DSS_modified\Capacitors.dss" For Output As #1

    ShuntCapacitor.MoveFirst
    Do While Not ShuntCapacitor.EOF
        Print #1, "New Capacitor." + ShuntCapacitor!DeviceNumber;
        If ShuntCapacitor!Location = "From" Then
            Print #1, " Bus1=" + ReplacePeriods(ShuntCapacitor!FromNodeID);
        ElseIf ShuntCapacitor!Location = "To" Then
            Print #1, " Bus1=" + ReplacePeriods(ShuntCapacitor!ToNodeID);
        Else
            Print #1, " ERROR ";
        End If
        Print #1, " Phases=3";
        Print #1, " Kvar=" + CStr(CDbl(ShuntCapacitor!KVARA) + CDbl(ShuntCapacitor!KVARB) +
            CDbl(ShuntCapacitor!KVARC));
        Print #1, " Kv=" + CStr(CDbl(ShuntCapacitor!KVLN) * 1.73205);
        Print #1, " Conn=wye"
        ShuntCapacitor.MoveNext
    Loop

        Close #1
End Sub
```

Public Sub MakeTransformers()

```
    Set Transformer = CurrentDb.OpenRecordset("Transformer", dbOpenTable)
    Set Tcode = CurrentDb.OpenRecordset("TransformerCodes", dbOpenDynaset)

    Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
files\June_loadAllc\DSS_modified\Transformers.dss" For Output As #1

    Dim conn1 As String
    Dim conn2 As String
    Dim phased As String
    Dim temp As String
    Dim neutralConn As String
    Dim kvPrimary As String
    Dim kvSecondary As String
    Dim kvAPrimary As String
    Dim kvASecondary As String
    Dim connection As String
    Dim devID As String
```

```
Dim x As Double
Dim r As Double
Dim k As Double

Transformer.MoveFirst
Do While Not Transformer.EOF

  temp = "[EquipmentID] LIKE '" + Transformer!DeviceID + "'"
  Tcode.MoveFirst
  Tcode.FindFirst temp
    If Tcode.NoMatch Then

    Else
      devID = ReplacePeriods(Transformer!DeviceID)
      secV = Right(devID, 5)
      secVLevel = Left(secV, 3)

      If Tcode!TransformerConnection = "Y_Y" Then

        Select Case Transformer!Phase
          Case "A"
            neutralConn = ".1.4"
            connection = "1"
          Case "B"
            neutralConn = ".2.4"
            connection = "1"
          Case "C"
            neutralConn = ".3.4"
            connection = "1"
          Case "ABC"
            neutralConn = ".1.2.3.4"
            connection = "3"
        End Select
      Else
        Select Case Transformer!Phase
          Case "A"
            neutralConn = ".1"
            connection = "1"
          Case "B"
            neutralConn = ".2"
            connection = "1"
          Case "C"
            neutralConn = ".3"
            connection = "1"
          Case "ABC"
            neutralConn = ".1.2.3"
            connection = "3"
        End Select
      End If

    Select Case Tcode!TransformerConnection
      Case "Yg_Yg"
```

```
      conn1 = "wye"
      conn2 = "wye"
   Case "D_Yg"
      conn1 = "delta"
      conn2 = "wye"
   Case "Y_Y"
      conn1 = "wye"
      conn2 = "wye"
   Case "D_D"
      conn1 = "delta"
      conn2 = "delta"
   Case "DO_DO"
      conn1 = "delta"
      conn2 = "delta"
   Case "YO_D"
      conn1 = "wye"
      conn2 = "delta"
End Select

Select Case Tcode!Type
   Case "SinglePhase"
      If connection = "1" Then

         If secVLevel = "240" Then
            phased = "1"
            kvPrimaryLL = Tcode!PrimaryVoltageKVLL
            kvPrimary = kvPrimaryLL / 1.7321
            kvSecondary = 0.12
            kvAPrimary = Tcode!NominalRatingKVA
            kvASecondary = Tcode!NominalRatingKVA
            k = Tcode!XRRatio
            x = ((k ^ 2 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
            r = ((1 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1

            Print #1, "New Transformer." + Format(Transformer!DeviceNumber);
            Print #1, " Phases=" + phased;
            Print #1, " Windings=3";
            Print #1, " XHL=" + Format(Round(x / 2, 2));
            Print #1, " XHt=" + Format(Round(x / 4, 2));
            Print #1, " XLt=" + Format(Round(x / 4, 2));
            Print #1, " wdg=1" + " Bus=" + ReplacePeriods(Transformer!FromNodeID) +
             neutralConn + ".0";
            Print #1, " Kv=" + kvPrimary + " Kva=" + kvAPrimary + " %R=" + Format(Round(r / 2,
             2)) + " Conn=" + conn1;
            Print #1, " wdg=2" + " Bus=" + ReplacePeriods(Transformer!ToNodeID) + ".1.0";
            Print #1, " Kv=" + kvSecondary + " Kva=" + kvASecondary + " %R=" + Format(Round(r
             / 4, 2)) + " Conn=" + conn1;
            Print #1, " wdg=3" + " Bus=" + ReplacePeriods(Transformer!ToNodeID) + ".0.2";
            Print #1, " Kv=" + kvSecondary + " Kva=" + kvASecondary + " %R=" + Format(Round(r
             / 4, 2)) + " Conn=" + conn1
```

```
        Else
          phased = "1"
          kvPrimaryLL = Tcode!PrimaryVoltageKVLL
          kvPrimary = kvPrimaryLL / 1.7321
          kvSecondaryLL = Tcode!SecondaryVoltageKVLL
          kvSecondary = kvSecondaryLL / 1.7321
          kvAPrimary = Tcode!NominalRatingKVA
          kvASecondary = Tcode!NominalRatingKVA
          k = Tcode!XRRatio
          x = ((k ^ 2 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
          r = ((1 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
          Print #1, "New Transformer." + Format(Transformer!DeviceNumber);
          Print #1, " Phases=" + phased;
          Print #1, " Wdg=1";
          Print #1, " Bus=" + ReplacePeriods(Transformer!FromNodeID) + neutralConn;
          Print #1, " Conn=" + conn1 + " Kv=" + kvPrimary + " Kva=" + kvAPrimary + " %R=" +
           Format(Round(r / 2, 2));
          Print #1, " Wdg=2";
          Print #1, " Bus=" + ReplacePeriods(Transformer!ToNodeID) + neutralConn;
          Print #1, " Conn=" + conn2 + " Kv=" + kvSecondary + " Kva=" + kvASecondary + "
           %R=" + Format(Round(r / 2, 2));
          Print #1, " XHL=" + Format(Round(x, 2))

        End If

      Else
        phased = "3"
        kvPrimary = Tcode!PrimaryVoltageKVLL
        kvSecondary = Tcode!SecondaryVoltageKVLL
        kvAPrimary = 3 * Tcode!NominalRatingKVA
        kvASecondary = 3 * Tcode!NominalRatingKVA
        k = Tcode!XRRatio
        x = ((k ^ 2 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
        r = ((1 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
        Print #1, "New Transformer." + Format(Transformer!DeviceNumber);
        Print #1, " Phases=" + phased;
        Print #1, " Wdg=1";
        Print #1, " Bus=" + ReplacePeriods(Transformer!FromNodeID) + neutralConn;
        Print #1, " Conn=" + conn1 + " Kv=" + kvPrimary + " Kva=" + kvAPrimary + " %R=" +
          Format(Round(r / 2, 2));
        Print #1, " Wdg=2";
        Print #1, " Bus=" + ReplacePeriods(Transformer!ToNodeID) + neutralConn;
        Print #1, " Conn=" + conn2 + " Kv=" + kvSecondary + " Kva=" + kvASecondary + " %R="
          + Format(Round(r / 2, 2));
        Print #1, " XHL=" + Format(Round(x, 2))

      End If

    Case "ThreePhase"
      If connection = "1" Then
        phased = "1"
        kvPrimaryLL = Tcode!PrimaryVoltageKVLL
```

```
            kvPrimary = kvPrimaryLL / 1.7321
            kvSecondaryLL = Tcode!SecondaryVoltageKVLL
            kvSecondary = kvSecondaryLL / 1.7321
            kvAPrimary = Tcode!NominalRatingKVA / 3
            kvASecondary = Tcode!NominalRatingKVA / 3
            k = Tcode!XRRatio
            x = ((k ^ 2 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
            r = ((1 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
            Print #1, "New Transformer." + Format(Transformer!DeviceNumber);
            Print #1, " Phases=" + phased;
            Print #1, " Wdg=1";
            Print #1, " Bus=" + ReplacePeriods(Transformer!FromNodeID) + neutralConn;
            Print #1, " Conn=" + conn1 + " Kv=" + kvPrimary + " Kva=" + kvAPrimary + " %R=" +
               Format(Round(r / 2, 2));
            Print #1, " Wdg=2";
            Print #1, " Bus=" + ReplacePeriods(Transformer!ToNodeID) + neutralConn;
            Print #1, " Conn=" + conn2 + " Kv=" + kvSecondary + " Kva=" + kvASecondary + " %R="
               + Format(Round(r / 2, 2));
            Print #1, " XHL=" + Format(Round(x, 2))

          Else
            phased = "3"
            kvPrimary = Tcode!PrimaryVoltageKVLL
            kvSecondary = Tcode!SecondaryVoltageKVLL
            kvAPrimary = Tcode!NominalRatingKVA
            kvASecondary = Tcode!NominalRatingKVA
            k = Tcode!XRRatio
            x = ((k ^ 2 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1
            r = ((1 / (1 + k ^ 2)) ^ (1 / 2)) * Tcode!Z1

            Print #1, "New Transformer." + Format(Transformer!DeviceNumber);
            Print #1, " Phases=" + phased;
            Print #1, " Wdg=1";
            Print #1, " Bus=" + ReplacePeriods(Transformer!FromNodeID) + neutralConn;
            Print #1, " Conn=" + conn1 + " Kv=" + kvPrimary + " Kva=" + kvAPrimary + " %R=" +
               Format(Round(r / 2, 2));
            Print #1, " Wdg=2";
            Print #1, " Bus=" + ReplacePeriods(Transformer!ToNodeID) + neutralConn;
            Print #1, " Conn=" + conn2 + " Kv=" + kvSecondary + " Kva=" + kvASecondary + " %R="
               + Format(Round(r / 2, 2));
            Print #1, " XHL=" + Format(Round(x, 2))
          End If
      End Select

      End If
     Transformer.MoveNext
 Loop
   Close #1

End Sub
```

```
Public Sub MakeBusCoords()

   Set BusCoordinates = CurrentDb.OpenRecordset("BusCoordinates", dbOpenTable)

   Open "D:\Documents and Settings\Anamika\My Documents\EV-research\OpenDSS-
         files\June_loadAllc\DSS_modified\Buscoords.dss" For Output As #1

   BusCoordinates.MoveFirst
   Do While Not BusCoordinates.EOF
      Print #1, ReplacePeriods(BusCoordinates!NodeID) + ", ";
      Print #1, BusCoordinates!x + ", ";
      Print #1, BusCoordinates!Y

      BusCoordinates.MoveNext
   Loop

   Close #1
End Sub
```

OPENDSS FILES

Code Snippet for Line.DSS

```
New Line.OH_OH_PRI_14267 Bus1=926006-703_684402-721.3 Bus2=2826_5970.3
Linecode=OH-1/0_AL_1N_ARMLESS_1/0_AL Length=35.106268 Phases=1
enabled=True Switch=False Units=m
New Line.OH_OH_SEC_2254894 Bus1=1768_549915.1 Bus2=920364-895_691782-
932.1 Linecode=OH-2-#2_CU-1-#2_CU-OW Length=6.096018 Phases=1
enabled=True Switch=False Units=m
...
```

Code Snippet for Loads.DSS

```
!New Load.5000015468_B Bus1=USAGEPOINT_1274515.2 Phases=1 Conn=wye
Model=1 kV=0.2771 kW=0.000000 PF=0 daily=R1 NumCust=0.000000
New Load.5000011901_A-1 Bus1=USAGEPOINT_1275221.1.0 Phases=1 Conn=wye
Model=1 kV=0.12 kW=2.7616 PF=-0.99853897 daily=R2 NumCust=1.000000
New Load.5000011901_A-2 Bus1=USAGEPOINT_1275221.2.0 Phases=1 Conn=wye
Model=1 kV=0.12 kW=2.7616 PF=-0.99853897 daily=R2 NumCust=1.000000
...
```

Code Snippet for LineCodes.DSS

```
New Linecode.OH-1/0AL_3_UNKNWN Nphases=3 R1=0.602854 X1=0.453203
R0=1.050256 X0=1.558434 C1=0.0000097678 C0=0.0000048076 Units=km
baseFreq=60 Normamps=240.000000 Emergamps=240.000000
New Linecode.OH-1P_#8CU_#8N Nphases=3 R1=0.121800 X1=0.393161
R0=0.266190 X0=1.041792 C1=0.0000110998 C0=0.0000055968 Units=km
baseFreq=60 Normamps=1.000000 Emergamps=1.000000
...
```

Code Snippet for Transformers.DSS

```
New Transformer.2780_5293 Phases=1 Windings=3 XHL=0.83 XHt=0.42
XLt=0.42 wdg=1 Bus=2780_5293.1.0 Kv=7.96720743606027 Kva=37.000000
%R=0.64 Conn=wye wdg=2 Bus=2780_5293-1.1.0 Kv=0.12 Kva=37.000000
%R=0.32 Conn=wye wdg=3 Bus=2780_5293-1.0.2 Kv=0.12 Kva=37.000000
%R=0.32 Conn=wye
New Transformer.2441_5139 Phases=1 Windings=3 XHL=0.87 XHt=0.44
XLt=0.44 wdg=1 Bus=2441_5139.3.0 Kv=7.96720743606027 Kva=50.000000
%R=0.67 Conn=wye wdg=2 Bus=2441_5139-1.1.0 Kv=0.12 Kva=50.000000
%R=0.34 Conn=wye wdg=3 Bus=2441_5139-1.0.2 Kv=0.12 Kva=50.000000
%R=0.34 Conn=wye
...
```

Code Snippet for Capacitors.DSS

```
New Capacitor.63 Bus1=63 Phases=3 Kvar=900 Kv=13.8044385 Conn=wye
New Capacitor.61 Bus1=61 Phases=3 Kvar=450 Kv=13.8044385 Conn=wye
New Capacitor.62 Bus1=62 Phases=3 Kvar=900 Kv=13.8044385 Conn=wye
...
```

Code Snippet for LoadShape.DSS

```
New LoadShape.lshape240-16_1 Npts = 1440 Interval = (1 60 /) mult =
(File=LoadShape_PEV\6pm-8am\lshape240-16_1.txt)
New LoadShape.lshape240-16_2 Npts = 1440 Interval = (1 60 /) mult =
(File=LoadShape_PEV\6pm-8am\lshape240-16_2.txt)
New LoadShape.lshape240-16_3 Npts = 1440 Interval = (1 60 /) mult =
(File=LoadShape_PEV\6pm-8am\lshape240-16_3.txt)
...
```

Code Snippet for pevLoad.DSS

```
New Load.pev1_2696_14018 Bus1=USAGEPOINT_1274924.1.2 Phases=1 Conn=wye
Model=1 kV=0.24 kW=3.456 PF=1 Daily = lshape240-16_4 NumCust=1.000000
New Load.pev2_2696_14018 Bus1=USAGEPOINT_1275405.1.2 Phases=1 Conn=wye
Model=1 kV=0.24 kW=3.456 PF=1 Daily = lshape240-16_5 NumCust=1.000000
New Load.pev3_2696_14018 Bus1=USAGEPOINT_1275579.1.2 Phases=1 Conn=wye
Model=1 kV=0.24 kW=3.456 PF=1 Daily = lshape240-16_6 NumCust=1.000000
...
```

Code Snippet for an example master.DSS file

```
Clear
New Circuit.JUNE_JUNE Bus1=CB_17 pu=1.029 r1=0.029518 x1=0.483908
r0=0.027423 x0=1.302895 basekv=13.8

Redirect LineCodes.dss
Redirect Lines.dss
Redirect Transformers.dss
Redirect loadshape.dss
Redirect Loads.dss
Redirect Capacitors.dss


!Redirect pev2076_5667-distr

Set voltagebases = [13.8, 4.16, 2.4, 0.24]
CalcVoltageBases


New monitor.M_oh_sec_2255727 element = Line.OH_oh_sec_2255727
terminal=2 mode=0

New Energymeter.PEV Element= Transformer.2076_5667 Terminal=1

set casename=ExampleCase
set mode=daily number= 24
set demand=true          ! demand interval ON

solve

Export Monitors M_oh_sec_2255727
```

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